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SALES hereby certify that annexed is a true copy of the Provisional specification
in connection with Application No. 2003902270 for a patent by ORIGIN
ENERGY SOLAR PTY LTD as filed on 09 May 2003.



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Patents Act 1990

PROVISIONAL SPECIFICATION FOR THE INVENTION ENTITLED:

Separating and Assembling Semiconductor Strips

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This invention is best described in the following statement:

SEPARATING AND ASSEMBLING SEMICONDUCTOR STRIPS

FIELD OF THE INVENTION

5 The present invention relates generally to semiconductor processing, and in particular to assembling arrays of semiconductor strips.

BACKGROUND

10 The photovoltaic solar cell industry is highly cost sensitive in terms of the efficiency of the voltage produced by a solar cell and the cost of producing the solar cell. As only a low percentage of the total thickness of a solar cell is used to generate voltage, it is increasingly important to minimise the thickness of the solar cell and yield more solar cells from a wafer.

15 International (PCT) Publication No. WO 02/45143 (PCT/AU01/01546) published on 06 June 2002 and entitled "Semiconductor Wafer Processing to Increase the Usable Planar Surface Area" describes "sliver" solar cells and a method of making such sliver solar cells to increase the usable surface area of a semiconductor wafer. The wafer has a substantially planar surface and a thickness dimension at a right angle to the substantially planar surface and is typically single crystal silicon or multicrystalline silicon.

25 In the method of International Publication No. WO 02/45143, a strip or sliver thickness is selected for division of the wafer into several strips or slivers. A technique is then selected for cutting the wafer into the strips at an angle to the substantially planar surface, in which the combined strip thickness and width of wafer removed by the cutting is less than the thickness of the wafer. The wafer is cut into strips using the selected technique, and the strips are separated from each other. The faces of the strips that were previously at an angle to the surface of the wafer become the faces of the strips exposed as a result of cutting the wafer and separating the strips from each other.

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 Fig. 1(a) illustrates a silicon wafer 3 formed by standard crystal growth and wafering techniques. The wafer 3 may be at least 0.5mm thick and typically about 1mm

thick and can be single-crystal or a multi-crystalline wafer. In the method of International Publication No. WO 02/45143, a series of parallel channels or slots 2 is formed in the wafer 3. The slots are typically 0.05mm wide, and the pitch of the slots is typically 0.1mm. In this manner thin parallel strips of silicon 1 are formed, about 0.05mm wide. Because the slots 2 do not extend all the way to the edges of wafer 3, a frame 5 of uncut silicon holds the strips 1 in place. Frame 5 is typically 5mm wide on each side. Slots 2 may be formed using any of a number of techniques, including those referred to in International Publication No. WO 02/45143.

Fig. 1 (b) is an enlarged vertical cross-section through the wafer 3 along line A-A showing strips 1 and spaces 2 in cross-sectional view.

Fig. 2 illustrates an arrangement of strips or slivers fabricated as solar cells 20 with a parallel connection and a gap between cells. The cells 20 are arranged on a substrate 21 as shown. Electrically conductive tracks 16 may be formed, for example, so that all the p polarity contacts 32 are electrically connected together at one end of the cells, while the n polarity contacts 33 are electrically connected together at the other end of the cells.

As the strips or slivers of semiconductor readily warp and bend but at the same time are quite brittle, the slivers disadvantageously may fracture or be damaged when separated from the wafer. Further, the faces of all slivers must all be configured with the same face as shown as cells 20 in Fig. 2, or differences in polarity may occur. Still further, the slivers may disadvantageously stick together.

Therefore, a need exists for separating strips or slivers of semiconductor material from wafers and assembling those separated strips or slivers.

SUMMARY

In accordance with a first aspect of the invention, there is provided a method of separating elongated semiconductor strips from a wafer of semiconductor material. A plurality of elongated semiconductor strips formed in a wafer in a substantially parallel

manner with respect to each other are provided. The wafer has a substantially planar surface and a thickness dimension at a right angle to the substantially planar surface. The wafer also has a frame portion(s) at opposite ends of the semiconductor strips connecting the strips to the wafer. The semiconductor strips each have a width at least substantially
5 equal to the wafer thickness and a thickness dimension of the strip less than the width. At least one of the elongated semiconductor strips lengthwise forms an edge of the wafer or being nearest adjacent the edge. A vacuum is applied to the elongated semiconductor strip forming the edge or being adjacent to the edge. The wafer and a source of the vacuum are displaced.

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In accordance with a second aspect of the invention, there is provided a method of assembling a plurality of elongated semiconductor strips separated from a wafer of semiconductor material into an array of the strips. One of the elongated semiconductor strips is received at a predetermined position of at least one belt oriented lengthwise
15 across the belt. The belt is moved in a given direction by a predetermined distance greater than the width of the elongated semiconductor strip. The receiving and moving steps are repeated until all of the elongated semiconductor strips have been processed.

In accordance with a third aspect of the invention, there is provided a method of
20 assembling an array of elongated semiconductor strips on a substrate. Adhesive material is deposited on the substrate in a predetermined manner. Vacuum is applied to each one of the elongated semiconductor strips to maintain the strips in the array. The array is a predefined arrangement of the strips. The array of elongated semiconductor strips is transferred to the substrate, and a face of each elongated semiconductor strip is brought
25 into contact with a portion of the adhesive material. The vacuum applied to each elongated semiconductor strip is reduced or ceased to provide the array of elongated semiconductor strips located in situ on the substrate and adhering to the substrate.

In accordance with a fourth aspect of the invention, there is provided a method of
30 assembling an array of elongated semiconductor strips on a substrate. The elongated semiconductor strips are formed in a wafer in a substantially parallel manner with respect to each other. The wafer has a substantially planar surface and a thickness dimension at a

right angle to the substantially planar surface. The wafer has a frame portion(s) at opposite ends of the semiconductor strips connecting the strips to the wafer. An elongated semiconductor strip is separated from the wafer using vacuum applied to the elongated semiconductor strip forming an edge or being adjacent to an edge of the wafer.

5 The wafer is displaced from a source of the vacuum relative by a predetermined distance. The elongated semiconductor strip is received on at least one first belt oriented lengthwise across the belt. The at least one first belt is moved in a given direction by a predetermined distance greater than the width of the elongated semiconductor strip. The foregoing steps are repeated until all of the elongated semiconductor strips have been

10 processed.

In another aspect of the invention, there is provided a device, comprising a substrate, an array of elongated semiconductor strips, adhesive material, and electrically conductive material. The elongated semiconductor strips are separated from a wafer of

15 semiconductor material, and each have a width substantially equal to the wafer thickness and a thickness dimension of the strip less than the width. The adhesive material is deposited between the substrate and a face of each elongated semiconductor strip to adhere the substrate and each elongated semiconductor together. The face has the width of the elongated semiconductor strip as one of its dimensions. The electrically conductive

20 material is deposited on the substrate connecting at least two of the elongated semiconductor strips together.

In accordance with further aspects of the invention, there are provided apparatuses and systems for implementing the methods in accordance with the foregoing aspects of

25 the invention. These and other aspects of the invention are set forth hereinafter

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention are described, by way of example only, with reference to the accompanying drawings, in which:

30 Figs 1(a) and 1(b) are a schematic diagram showing top and cross sectional views of a semiconductor wafer following the formation of slots;

Fig. 2 is a schematic diagram illustrating the arrangement of semiconductor strips or slivers and their electrical interconnection;

Figs. 3(a) to 3(d) are schematic diagrams illustrating a semiconductor wafer having one or more regions of strips or slivers formed in the wafer;

5 Fig. 4 is a schematic diagram illustrating a semiconductor wafer having a region of strips or slivers that are unevenly spaced or warped in the wafer due to flexibility of the strips or slivers;

Fig. 5 is a block diagram of a vacuum source with which embodiments of the invention may be practiced;

10 Figs 6(a) to 6(d) are schematic diagrams illustrating a process of separating strips or slivers from the semiconductor wafer of Fig. 4;

Fig. 7 is a schematic diagram illustrating a weakened region of the wafer shown in Fig. 3(d);

15 Fig. 8 is a schematic diagram illustrating an arrangement of a vacuum source and a first pair of castellated belts for receiving slivers or strips separated from the wafer by the vacuum source;

Fig. 9 is a schematic diagram illustrating the first pair of belts of Fig. 8, a drum adapted to applying vacuum to slivers or strips, and a second pair of belts;

20 Fig. 10 is a schematic diagram illustrating a reference for adjusting the alignment of slivers arranged in the second pair of belts of Fig. 9;

Fig. 11 is a flow diagram illustrating a process of separating strips or slivers from a wafer of semiconductor material;

Fig. 12 is an image showing six wafers with slivers formed in each of the wafers;

25 Figs. 13(a) to 13(c) are images showing a yoke for holding a wafer having slivers or strips formed in the wafer;

Fig. 14 is an image of a robotic device for separating strips or slivers from a wafer of semiconductor material;

Fig. 15 is an image of an arm of the robotic device of Fig. 14 for holding a yoke that holds a wafer;

30 Fig. 16 is an image of a yoke connected to the arm of Fig. 15;

Figs. 17, 18, and 19 are more detailed images of an assembly in the robotic device of Fig. 14 including a vacuum source or block disposed between a first pair of belts and a

mechanism for testing slivers or strips and removing defective slivers or strips from the belts;

Fig. 20 is a more detailed image of the mechanism of Fig. 17 for removing defective slivers or strips from the belts;

5 Figs. 21 and 22 are images of a drum in the belt assembly adapted to apply vacuum to slivers arranged in the belts;

Figs. 23 and 24 are images of a lifter/referencer for adjusting the alignment and spacing of slivers or strips;

10 Figs. 25 and 26 are images of transfer mechanism adapted to apply vacuum to slivers or strips in an array of slivers from spacing belts and/or lifter/reference and to transfer the array to a substrate;

Fig. 27 is a more detailed image of the vacuum block and belts of Figs. 17 to 19;

Fig. 28 is an image of an array of slivers or strips assembled on a substrate;

15 Figs. 29 to 31 are schematic diagrams illustrating the process of assembling an array of slivers on a substrate, including depositing electrically conductive material and adhesive material on the substrate;

Fig. 32 is a flow diagram illustrating a method of assembling several slivers separated from the wafer into an array of slivers;

20 Fig. 33 is flow diagram illustrating a method of refining the spacing between slivers using a second pair of belts; and

Fig. 34 is a flow diagram illustrating a method of assembling an array of slivers on a substrate.

DETAILED DESCRIPTION

25 A method and an apparatus are disclosed for separating elongated semiconductor strips from a wafer of semiconductor material. Further, a method and an apparatus are disclosed for assembling a plurality of elongated semiconductor strips separated from a wafer of semiconductor material into an array of the strips. Still further, a method and an apparatus are disclosed for assembling an array of elongated semiconductor strips on a
30 substrate. In the following description, numerous specific details, including semiconductor strip or sliver dimensions, the number of belts, spacings between belt

castellations, and the like are set forth. However, from this disclosure, it will be apparent to those skilled in the art that modifications and/or substitutions may be made without departing from the scope and spirit of the invention. In other circumstances, specific details may be omitted so as not to obscure the invention.

5

Overview

Fig. 11 is a flow diagram illustrating a process 1110 of separating strips or slivers from a wafer of semiconductor material in accordance with an embodiment of the invention. The strips are elongated in shape. Preferably, the wafer is single crystal
10 silicon or multi-crystalline (or poly-crystalline) silicon. However, other semiconductor materials may be practiced without departing from the scope and spirit of the invention. In step 1110, several elongated semiconductor strips formed in a wafer in a substantially parallel manner with respect to each other are provided. The wafer has a substantially planar surface and a thickness dimension at a right angle to the substantially planar
15 surface. The wafer also has one or more frame portions at opposite ends of the semiconductor strips connecting the strips to the wafer. The semiconductor strips each have a width substantially equal to the wafer thickness and less than a thickness dimension of the strip. A face of at least one of elongated semiconductor strips lengthwise forms an edge of the wafer or is nearest adjacent the edge. The wafer may be
20 moved so that the face of the elongated semiconductor strip is in close proximity to the source of the vacuum. In step 1120, vacuum is applied to the face of the elongated semiconductor strip forming the edge or being adjacent to the edge. In step 1130, the wafer and a source of the vacuum are displaced relative to each other a predetermined distance to separate the elongated semiconductor strip having vacuum applied to the
25 elongated semiconductor strip from the wafer.

The vacuum applied to the separated, elongated semiconductor strip is reduced and is preferably terminated (i.e., the vacuum ceases) and the separated, elongated semiconductor strip and the source of the vacuum are displaced relative to each other.

30

The steps of the method are repeatedly performed to separate two or more of the elongated semiconductor strips from the wafer. The source of the vacuum has a body

with at least one cavity formed in the body for providing the applied vacuum. The cavity adjacent the face of the elongated semiconductor strip is substantially the same in size as or smaller than a dimension of the face. Specific embodiments of vacuum sources, or vacuum blocks, are set forth hereinafter.

5

Preferably, the wafer is formed with weak points in portions of the wafer adjacent opposite ends of the elongated semiconductor strips. The weak points facilitate separation of the elongated semiconductor strip from the wafer. More preferably, the weak points are grooves formed in the wafer using any of a number of well-known techniques, including sawing and etching. Other methods of forming such weak points may be practiced without departing from the scope and spirit of the invention.

10

Preferably, the elongated semiconductor strips are utilized to form "sliver" photovoltaic solar cells. However, similarly configured semiconductor slivers or strips may be used to form other devices and circuits.

15

In the following description, embodiments of the invention are disclosed in detail utilising pairs of belts with castellations. However, the methods, apparatuses and systems may be practiced with other numbers of belts and configurations. For example, the methods, apparatuses and systems may be implemented using a single belt for each pair of belts described in detail below. Further, the belt may have grooves formed in it rather than castellations. For example, each belt may be porous to allow vacuum action through it, or the belt may have openings, have perforations, be woven, or the like, to enable use with the vacuum source. Other variations may be practiced without departing from the scope and spirit of the invention.

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Wafers with Slivers

Figs. 3(a) and 3(b) are schematic diagrams illustrating semiconductor wafers having at least one region of strips or slivers formed in the wafer. Hereinafter, such strips of semiconductor cut in the wafer are referred to as "slivers" for ease of description. A first configuration 300 of a semiconductor wafer 310 with several sliver portions 312, 314, 316 is depicted in Fig. 3(a). As can be seen from the Fig. 3(a), the portion 314 has

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slivers that are significantly longer than those of regions 312 and 316. Separate processes may be practiced to process the different length slivers, although essentially the same steps and equipment are utilized.

5 For ease of description, another configuration 350 is depicted in Fig. 3(b). A larger, single portion 352 of slivers characterizes this wafer 360 (otherwise identical to that 310 of Fig. 3(a)). A portion 370 of the wafer 360 is removed from the wafer 360 along the dashed line 380 using any of a number of well-known techniques. A face of at least one of elongated semiconductor strips lengthwise forms an edge of the wafer or is
10 nearest adjacent the edge. Fig. 3(c) shows the resulting configuration of the wafer 360 having a flat or straight edge 390. A frame(s) of uncut wafer material surrounds the slivers portion 352. A face of one of the slivers (i.e., an elongated semiconductor strip) lengthwise forms the edge 390 of the wafer 360 or is nearest adjacent the edge 390. The latter would be the case if slivers are progressively removed from the edge 390. Fig. 3(d)
15 is an elevation view showing the thickness of the wafer 360, with one sliver 352 (indicated by diagonal hashing) forming part of the edge 390, or being adjacent thereto. A dashed circle 700 indicates a portion of the wafer where the sliver 352 is connected to a frame portion of the wafer 360 and is shown in an enlarged view in Fig. 7.

20 While the slivers in Fig. 3(c) are shown formed at substantially right angles to the planar surface of the wafer, this need not be the case. For example, the slivers may be formed (e.g., etched) at an angle different than ninety degrees to form slivers that are wider than the thickness of the wafer. Thus, the width of a sliver may be at least substantially equal to the thickness of the wafer. This covers the case where the width is
25 slightly less than the thickness of the wafer, equal to the thickness, or greater than the thickness of the wafer.

 As shown in Fig. 7, the circle 700 shows an enlarged portion of the wafer 360. A weakened portion 710 is formed in the region between the sliver 352 (diagonal hashing)
30 and the frame (solid white). The weakened portion 710 is preferably a groove formed by sawing and may be 50% of the width of the face of the sliver 352, and may be larger (e.g., 60%). Such weakened portions 710 may be formed at opposite ends of the slivers

connected with the frame(s). Other techniques including etching may practiced to form the weakened portions.

While the slivers 352 shown in Figs. 3(a) to 3(d) have been depicted as
5 substantially straight or flat, the gaps formed between slivers may and frequently do produce deflections or warping of the slivers. For example, several slivers may be warped to as to have an S-shape lengthwise. The slivers may also stick together, or portions of slivers may break off from the wafer. Fig. 4 is a schematic diagram illustrating the configuration 400 of a semiconductor wafer 460 having a region 452 of
10 slivers, including slivers 470 and 480 that are unevenly spaced or warped in the wafer 460 due to flexibility of the slivers. The displacement or warping 470, 480, the thickness of the slivers, and the spaces between slivers are exaggerated in the Figure for purposes of illustration. Fig. 12 is an image showing six actual wafers 1210, 1220, 1230, 1240, 1250, and 1260 with slivers formed in each of the wafers, with which embodiments of the
15 invention may be practiced. The wafer 1230 has a portion of slivers that are regularly spaced. The wafers 1240 and 1260 have had a portion of the wafer removed to form an edge with slivers adjacent to the edge. Several of the slivers 1242 of the wafer 1240 have fragmented from the wafer 1240 indicating the brittleness and the fragility of slivers when handled. The wafer 1220 clearly shows a number of slivers formed in the wafer 1220 that
20 are warped or deflected (i.e., having a wave-like shape with irregular gaps), as indicated in Fig. 4. The wafers have weak points formed in portions of the wafers adjacent opposite ends of the slivers to facilitate separation of the slivers from the wafer. This may be done using sawing, or etching, or any of a number of other techniques. Again, the wafers are preferably single crystal silicon or multicrystalline silicon, but may be other types of
25 semiconductors.

Vacuum Source

The process 1100 of Fig.11 advantageously uses a vacuum source to apply vacuum to a sliver to separate the sliver from the wafer. Steps 1120 and 1130 use the
30 vacuum. Fig. 5 is a generic depiction of a vacuum source 500. The vacuum source 500 includes a solid body 510, which may be rectangular in form. The body 510 has one or more channels 520 formed through the body 510. The channels 520 are cylindrical in

form (indicated with dashed lines) with a circular or substantially circular orifice in the topmost surface of the source 500. More preferably, the vacuum source is a shaped vacuum block. Still further, while the channels 520 are cylindrical in form with circular orifices, it will be appreciated by those skilled in the art that other configurations of the block and channels may be practiced without departing from the scope and spirit of the invention. For example, the block may be circular, rather than rectangular in form. Still further, the channels 520 may be rectangular in form with square orifices rather than cylindrical in form with circular in form, for example. Many variations may be practiced provided that sufficient vacuum is created to separate a sliver in contact with the vacuum source 500 from the wafer. Vacuum pulls the sliver downwardly toward the vacuum source 500, as indicated by arrow 530. This is done by applying suction to the bottom surface of the block 510. Further details of vacuum sources and their equivalents are set forth hereinafter.

15 Separating Slivers from Wafer Using Vacuum Source

Figs 6(a) to 6(d) are schematic diagrams depicting the process of separating slivers from the semiconductor wafer 460 of Fig. 4. Again, the slivers portion 452 contains a number of warped or deflected slivers. While not shown in the Figure, slivers may also be broken partially or entirely from the wafer 460. The vacuum source 500 (body 510 with channels 520) is initially displaced by a predetermined distance relative to a sliver 630 forming the edge of the wafer 400.

In one embodiment as depicted in Fig. 6(b), the wafer 400 is moved toward the vacuum source 500, as indicated by arrow 610, so that the edge of the wafer abuts or is adjacent to the vacuum source 500. In an alternative embodiment, the vacuum source 500 may be moved so that it abuts or is adjacent to the wafer 400, rather than moving the wafer 400. Vacuum is then applied so that a face of the vacuum source having the orifices fastens the sliver 630. The wafer 400 and the vacuum source 500 are then displaced a predetermined distance, so that the weakened portions 710 of Fig. 7 snap or break and the sliver 630 is separated from the wafer 400. As shown in Fig. 6(c), the sliver continues to be in contact with the face of the vacuum source 500. This process is repeatedly carried out for each successive sliver most adjacent to the edge. Fig. 6(d)

shows how the wafer 400 is progressively moved toward the vacuum source 500 by the thickness of a sliver or related distance so that the vacuum source 500 removes inwardly positioned slivers 452 from the wafer 400.

5 As depicted in Fig. 6, the vacuum source 500 pulls of the sliver at a right angle relative to the plane of the wafer. However, this need not be the case. The slivers may be pulled off or extracted at other angles relative to the plane of the wafer.

10 A device or apparatus may be readily practiced using the foregoing method to separate slivers from the wafer of semiconductor material. As described in greater detail hereinafter, a yoke or jig is used to hold the wafer having slivers. Preferably, the yoke is coupled to a lever or arm of a robotic machine that can position a sliver adjacent to the vacuum source 500 and then displace the wafer and the vacuum source 500 relative to each other a predetermined distance to separate the sliver having vacuum applied to the
15 elongated semiconductor strip from the wafer.

Assembling Slivers into an Array Using Belts

 Another embodiment of the invention provides a method 3200 of assembling slivers, separated from a wafer of semiconductor material, into an array as shown in Fig.
20 32. In step 3210, one of the elongated semiconductor strips or slivers is received at predetermined positions of at least one belt oriented lengthwise across the belt. In step 3220, the belt is moved in a given direction by a predetermined distance greater than the width of the elongated semiconductor strip. In decision step 3230, a check is made to determine if all of the elongated semiconductor strips have been processed. If step 3230
25 returns false (NO), processing continues at step 3210. In this manner, the receiving and moving steps are repeated until all of the elongated semiconductor strips have been processed. If step 3230 returns true (YES), processing terminates. Further details of this process are set forth hereinafter with reference to Fig. 8. For example, the at least one belt may be porous to allow vacuum action through it, or the belt may have openings,
30 perforations, weaving, or the like, to enable use with the vacuum source.

A sliver oriented lengthwise is received at preferably a pair of parallel belts at predetermined positions of the parallel belts across the belts as depicted generally in Fig. 8. The drawing shows a configuration 800 of belts 810 and a vacuum source 500. The belts 810 are preferably castellated, having castellations or teeth projecting upwardly.

5 Several slivers 630 are shown each lying between an adjacent pair of castellations on each belt. A predetermined distance 820 separates adjacent castellations. The vacuum source 500 applies a vacuum to a face of the sliver 630 and is used to deliver the sliver at the predetermined position. The belts 810 move synchronously in a given direction by a predetermined distance greater than the width of the sliver. The predetermined distance is
10 preferably relative to the vacuum source 500. In this manner, the slivers 630 as depicted in Fig. 8 are fed forward. Again, the foregoing receiving and moving operations repeat until all of the slivers 630 have been processed.

While the belts 810 are depicted as being castellated timing belts, in an alternative
15 embodiment of the invention, the belts may be made of a tape-like fabric and have adhesive on a surface upon which the slivers 630 are received. Further, the belts may be made of mylar. This would allow lengths of assembled belts of slivers to be readily manufactured and cut to length or provided in predetermined lengths.

20 As depicted in Fig. 8, the castellated belts have a distance between adjacent castellations substantially wider than the width of the sliver. This permits a sliver to be placed readily between castellations of each belt without flipping over the sliver 630 and thereby changing its orientation vis-à-vis other slivers.

25 Apparatuses for Separating and Assembling Slivers

Another embodiment of the invention provides an apparatus for separating elongated semiconductor strips from a wafer of semiconductor material. This apparatus is preferably implemented as a robotic device 1400 shown in Fig. 14. The robotic device 1400 has a mechanism for holding a wafer with slivers formed in a substantially parallel
30 manner with respect to each other in the wafer (not shown). This holding function is implemented using a yoke 1300, or substantially U-shaped clamp, for securing a wafer as shown in Figs. 13(a) to 13(c). Fig. 13(a) shows an image of the yoke 1300 in assembled

form, and Figs. 13(b) and 13(c) show the yoke 1300 disassembled. The yoke 1300 comprises two U-shaped yoke plates 1320 and 1330 that can sandwich a wafer 1340 between the plates 1320 and 1330, which are held together with two screws 1330. The yoke plates 1310 and 1320 having holes with which registration holes in the wafer 1340 (not shown) can be used to align the wafer 1340 with the yoke plates 1310 and 1320.

An arm 1410 of the robotic device 1400 is shown generally in Fig. 14 and in greater detail in Fig. 15. The arm 1410 has depending elongated members spaced apart at one end forming a complementary shape to that of the yoke 1300 and has registration pins with which the yoke 1300 can be aligned. The yoke 1300 preferably connects to the arm 1410 magnetically. Fig. 16 is an image showing the yoke 1300 holding a semiconductor wafer 1600 connected to the arm or lever 1410. The holding function further has an elevator mechanism 1420 shown in Fig. 14 that can raise and lower the arm 1410 and hence the wafer 1600 relative to a vacuum source (not shown) in the assembly 1430 of Fig. 14. Thus the robotic device 1400 displaces the wafer 1600 and the vacuum source by moving the arm 1410 preferably. This implements the functionality of moving the wafer so that the face of a sliver is in close proximity to the vacuum source 1710. Alternatively, this functionality may be achieved by moving a vacuum source relative to a wafer that is held fixedly in place, so that the vacuum source is in close proximity to the face of the sliver. It will be apparent to those skilled in the art that the displacement of the wafer relative to the vacuum source can be achieved in other ways without departing from the scope and spirit of the invention. The displacement is a predetermined distance to separate the sliver from the wafer and can be programmably adjusted as slivers are removed from the wafer so that the slivers are progressively removed inwardly across the wafer.

Figs. 17, 18, 19 and 27 are images showing a vacuum source 1710 (or vacuum block) in the assembly 1430 of Fig. 14. The vacuum source 1710 applies vacuum to the face of a sliver (such as the lower sliver 2700 in Fig. 27 shown directly above channel orifices 1712 in Fig. 27. The body of the vacuum source 1710 is preferably made of metal but other materials may be used without departing from the scope and spirit of the invention. The vacuum source 1710 has a body with at least one cavity formed in the

body for providing the applied vacuum. The cavity or cavities are arranged in a surface of the body that can be placed adjacent the face of the sliver. The orifices are substantially the same in size as or smaller than a dimension of the face. While five circular orifices 1712 are depicted in Fig. 18 and 27, it will be appreciated by those skilled in the art that different numbers and shapes of orifices may be practiced without departing from the scope and spirit of the invention. The vacuum applied to the sliver may be reduced or terminated to release the sliver from the vacuum source 1710 following separation from the wafer, as described hereinafter. However, in the embodiment shown, the vacuum source may operate continuously at essentially the same level of vacuum.

The assembly 1430 has a pair of castellated belts 1700, each belt position on an opposite end of the vacuum source 1710, which is located between the belts 1700 so that the space between a pair of castellations in each belt are aligned with the orifices configured lengthwise in the top surface of the vacuum source 1710. The belts 1700 are flexible and may be made of materials such as rubber, plastic, elastomer and any other suitable material. A motor 1720 is used to turn the belts 1700 in step (i.e., in a programmed or regular manner) in cooperation with the operation of the arm 1410 and the vacuum source 1710. Movement of the belts 1700 displaces the separated sliver from the vacuum source 1710 relative to each other. A drum 1760 is provided at the opposite end of the belts relative to the motor 1720 for moving the belt. As described in greater detail hereinafter, the drum 1760 preferably has a vacuum source also.

A programmable logic controller (PLC) may be used to control and synchronise operation of the arm 1410 and elevating mechanism 1420, the vacuum source 1710, and the belts 1700 to repeatedly perform operations to separate two or more of the slivers from the wafer. A PLC is not shown in the drawings, but will be well understood by those skilled in the art. Numerous other processors and controllers may be practiced to implement these control and synchronization functions.

Figs. 17 to 21 and 27 also show a pair of rails 1730 above and parallel to the pair of belts 1700, which are positioned to prevent slivers from flipping over or lifting out of

the spaces between pairs of castellations in the belts 1700. The rails are rectangular in form and are made out of metal in this embodiment, although again other structures and materials may be utilized to achieve this functionality.

5 The assembly 1430 also can be arranged with a testing device to test the electrical properties of the slivers while located on the belt as each sliver passes over or is adjacent to the testing mechanism. The testing device is not shown in the Figures but may be positioned in the assembly 1730 at the position denoted generally by arrow 1740 in the image of Fig. 20. For example, the sliver may be tested by applying light from a light
10 source to the sliver (e.g. 1 sun) and measuring the resulting voltage produced by the sliver. The results of such testing can be reported to the controller, or other suitable mechanism, for removing defective slivers from the belt and maintaining information about the empty position in the belts 1700 that results. As indicated in Figs. 17 and 20, a vacuum source 1750 is positioned in the assembly 1730 to remove defective slivers, after
15 testing and in response to the testing results. Preferably, the vacuum source 1750 for removing defective slivers is positioned above the belts 1700, after the testing mechanism location but before the drum 1760. The removal of such a defective sliver from the belts is tracked for the purposes of further processing using the belts.

20 Projections 1770 of Fig. 27 are located on opposite sides outside of the belts 1700. In the Figure, the projections are implemented by adjustable screws. These projections are used to remove jags from the internal edges of the wafer frames after slivers have snapped off. Other techniques and devices may be practiced for this purpose without departing from the scope and spirit of the invention.

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Refining Spacing Between Slivers Using a Second Pair of Belts

Fig. 33 is flow diagram illustrating a method 3300 of refining the spacing between slivers using a second pair of belts. In step 3310, each elongated semiconductor strip is transferred from the at least one belt to at least one other belt located adjacent thereto.
30 The transferring step preferably involves applying vacuum to each elongated semiconductor strip during movement of the other belt. The other belt has castellations with a distance between adjacent castellations greater than the width of an elongated

semiconductor strip but substantially less than adjacent castellations of the at least one belt that received the elongated semiconductor strip. In step 3230, the at least one other belt moves in a given direction by a predetermined distance. This distance is greater than the width of the elongated semiconductor strip. In decision step 3330, a check is made to
5 determine if at least a portion, or all, of the elongated semiconductor strips have been processed forming the array of strips. If step 3330 returns false (NO), processing continues at step 3310. In this manner, the transferring and moving steps are repeated until the portion of strips has been processed. Otherwise, if step 3330 returns true (YES), processing terminates. Further details of this processing are described hereinafter with
10 reference to Fig. 9.

The spacing between slivers may be reduced using the mechanism 900 of Fig. 9. In particular, Fig. 9 illustrates the first pair of belts 810 of Fig. 8, a drum 10 adapted to apply vacuum via one or more orifices 920 to slivers, and a second pair of belts 940.
15 While castellations are not shown in Fig. 9 to simplify the drawing, it will be readily appreciated visually from the drawing that the spacing 950 of slivers on the second pair of belts 940 is significantly smaller than the distance 820 of the first pair of belts in Figs. 8 and 9. The drum or roller 910 has orifices in alignment with the space between castellations in the belts 810 and is used to apply vacuum to a face of a sliver so that the
20 sliver can be delivered by rotation about the drum 910 in the smaller spaced 950 castellations (not shown) of the second pair of belts 940. Each sliver is transferred from the first pair of belts 810 to the second pair of belts 940 located adjacent thereto. The distance 950 is greater than the width of a sliver but substantially less than the distance 820. The second pair of belts 940 moves in a given direction by a predetermined distance
25 greater than the width of the sliver. The foregoing steps are repeated until at least a portion of the strips has been processed, thereby forming the array of strips.

The use of two pairs of belts in the foregoing manner is advantageous in that a first pair of belts with widely spaced castellations is used to receive the slivers from the
30 wafer. The slivers can then be tested, and defective slivers removed before the remaining slivers are delivered to the more closely spaced castellations of the second belts in a controlled manner. Attempting to deliver slivers directly from the wafer to the second

pair of belts with closely spaced castellations could disadvantageously result in a number of slivers flipping so that not all of the slivers are facing in the same direction once removed from the wafer. Where the slivers are used in devices such as sliver solar cells, this could result in voltages being produced with opposite polarities in series, for example. This would result in reduced efficiencies of the solar modules or arrays.

Gaps in the first belts due to removed/missing slivers are tracked and taken into account to ensure that the second belts are properly populated without unintended gaps in the resulting array.

10

Apparatus for Refining Spacing Between Slivers

Figs 20, 21 and 22 illustrate part of the assembly 1430 that implements the upper belt assembly in Fig. 9. This is part of the apparatus for assembling slivers separated from a wafer of semiconductor material into an array of slivers. The two parallel belts 1700 receive at predetermined positions one of slivers oriented lengthwise across the belts 1700. The motor 1720 of Fig. 17 moves the belts 1700 in a given direction by a predetermined distance greater than the width of the sliver. A controller (not shown) coupled to the motor repeats the receiving and moving operations until all of the slivers have been processed. The apparatus also has at least two further belts (not shown in Figs 20, 21, and 22, but depicted schematically in Fig. 9) located adjacent to and below the two belts 1700.

The drum 1760 in combination with the belts 1700 implements the functionality of transferring sliver from the two belts 1700 to the two further belts. The drum 1760 has an arrangement of vacuum channel orifices 1762 aligned with the spacing between adjacent castellations 1702 in each belt 1700 as the belts 1700 rotate about the drum 1760. The two further belts each have castellations with a distance between adjacent castellations greater than the width of a sliver but substantially less than adjacent castellations of the two belts that received the sliver. The drum 1760 comprises a second vacuum source applying vacuum to each strip during movement of the two further belts and ceasing the vacuum to effect transfer of each sliver. A motor moves the two further belts in a given direction by a predetermined distance greater than the width of the

30

elongated semiconductor strip. Again, the controller repeats the transferring and moving operations until at least a portion of the elongated semiconductor strips have been processed forming the array of strips.

5 Fig. 10 is a schematic diagram of a lifter/referencer 1000 for aligning and further adjusting the spacing of the slivers. In the lifter/referencer 1000, an outer set of castellations 1030 on each side of the lifter/referencer are displaced with respect to an inner set of castellations 1050 on a slide member 1040. The lifter/referencer 1000 is used to closely space together slivers 630 by a predetermined distance 1020 less than the
10 spacing between adjacent castellations in the second pair of belts 940. Preferably, the lifter/referencer 1000 is positioned between the belts 940 to make fine spacing adjustments.

 Figs. 23 and 24 are images of a lifter/referencer 2300 utilising the principles of the
15 lifter/referencer 1000 of Fig. 10. As can be clearly seen in Fig. 24, the outer castellations 2310 on opposite outer sides of the lifter/referencer 2300 are separated by a small distance close to the width of the slivers and an inner set of castellations 2330 is slightly displaced relative to the outer castellations 2310. The inner castellations are connected to a slide member 2320. The inner and outer castellations 2310, 2330 can be displaced
20 relative to each other to fine-tune the position of slivers in the array.

Assembling an Array of Slivers on a Substrate

 Fig. 34 illustrates a method 3400 of assembling an array of elongated semiconductor strips on a substrate. In step 3410, adhesive material is applied on the
25 substrate in a predetermined manner. In step 3420, vacuum is applied to each one of the elongated semiconductor strips to maintain the strips in the array. The array is a predefined arrangement of the strips. In step 3430, the array of elongated semiconductor strips is transferred to the substrate, and a face of each elongated semiconductor strip is brought into contact with a portion of the adhesive material. In step 3440, the vacuum
30 applied to each elongated semiconductor strip ceases to provide the array of elongated semiconductor strips located in situ on the substrate and adhering to the substrate.

Fig. 28 is an image showing the configuration of an array 2820 of slivers assembled on a substrate 2810 using this method 3400.

5 Figs. 25 and 26 are images of a transfer mechanism 2500 adapted to apply vacuum to slivers or strips in an array of slivers in spacing belts and/or lifter/referencer and to transfer the array to a substrate. The transfer mechanism 2500 is shown upside down to illustrate castellations and vacuum channel orifices 2510. The castellations are spaced to align with the slivers on the belt 940. Vacuum can be applied to the array of slivers on the belt to lift the slivers and then move them using the transfer mechanism, which is
10 preferably implemented with a robotic arm to transfer the array of slivers to the substrate. The robotic arm may implement rotary motion and/or use variable orientation for placement of the array on a substrate. Numerous variations are possible without departing from the scope and spirit of the invention.

15 The assembly of the array of slivers is now described with reference to Figs. 29 to 31. For ease of illustration only, the initial configuration 2900 shows the substrate 2910 with a number of pads of electrical conductive material formed on the substrate. The pads may be an epoxy that is dispensed or printed onto the substrate. The electrically conductive material is used to electrically connect two or more of the elongated
20 semiconductor strips when deposited on the substrate. Fig. 30 illustrates the configuration 3000 where adhesive material is subsequently applied or dispensed on the substrate, preferably as strips 2930, configured between the pads 2920. The adhesive material may also be stamped on the substrate. Alternatively, the adhesive strips may be put on the substrate before the pads of electrically conductive material. The process
25 shown in Figs. 29 and 30 may be practiced for example where the substrate is pre-printed with electrically conductive material for example. Further, the adhesive material may be applied before or after the electrically conductive material, or vice versa.

30 In Fig. 31, the final configuration 3100 shows the slivers 2930 transferred to the substrate using the transfer mechanism 2500, resulting in the strips adhering to the substrate and being electrically interconnected in any of a number manners.

The device shown in Fig. 31 comprises the substrate 2910, an array of elongated semiconductor strips 2940, adhesive material 2930, and electrically conductive material 2920. Again the strips 2940 are separated from a wafer of semiconductor material, and each has a width substantially equal to the wafer thickness and a thickness dimension of the strip 2940 less than the width. The adhesive material 2930 is deposited between the substrate 2910 and a face of each elongated semiconductor strip 2940 to adhere the substrate 2910 and each elongated semiconductor strip 2940 together. The face has the width of the elongated semiconductor strip 2940 as one of its dimensions. The electrically conductive material 2920 is deposited on the substrate 2910 connecting at least two of the elongated semiconductor strips 2940 together. Each elongated semiconductor strip 2940 may comprise a sliver photovoltaic solar cell. Still further, the device is a solar cell module.

The substrate may be glass with a reflective surface on one side so that incident light between the strips in the array is reflected at least partially to the bottom surface of slivers in the array. Still further, the substrate may be a Lambertian reflector. Optical adhesive is preferably used between the slivers and the substrate. Once the electrically conductive connections between strips is formed, an encapsulant may be applied over the array. Metal connections may be used to effect the electrically conductive connections alternatively. A transparent glass plate or other suitable material may then be adhered, for example using adhesive, on top of this encapsulant to form a sandwich like structure with the array of slivers located internally. Dependent upon the spacings of the at least one second belt, the elongated semiconductor strips may be separated by roughly one, two, or three strip widths.

An apparatus for assembling an array of slivers on a substrate utilizes a mechanism for applying adhesive material on the substrate in strips. This may be done by dispensing or stamping the adhesive material, for example. The transfer mechanism 2500 has a vacuum source applying vacuum to each one of the slivers to maintain the strips in the array, the array being a predefined arrangement of the strips. Further, the transferring mechanism is used to transfer the array to the substrate 2910 and bring a face of each sliver into contact with a portion of the adhesive material 2930. The vacuum source 2510

then ceases the vacuum applied to each sliver to provide the array of slivers located in situ on the substrate and adhering to the substrate.

Further aspects of the method of Fig. 34 can be carried out by the apparatus.

5

Assembling an Array of Slivers on a Substrate

In accordance with another embodiment of the invention, there is provided a method of assembling an array of slivers on a substrate. A sliver is separated from the wafer using vacuum applied to a face of the sliver forming an edge or being adjacent to an edge of the wafer. The wafer is displaced from a source of the vacuum relative by a predetermined distance. The sliver is received on a first pair of parallel belts oriented lengthwise across the belts. The belts are moved in a given direction by a predetermined distance greater than the width of the sliver. These operations are repeatedly carried out until all of the slivers have been processed. The first pair of belts is castellated and has a distance between adjacent castellations substantially wider than the width of the sliver. Each sliver is transferred from the first pair of belts to a second pair of belts using vacuum. The second pair of belts each have castellations with a distance between adjacent castellations greater than the width of an sliver but substantially less than adjacent castellations of the first pair of belts. The second pair of belts are moved in a given direction by a predetermined distance greater than the width of the sliver. This is done in synchronization with the first pair of belts. These operations are carried out until at least a portion of the slivers have been processed forming the array of strips.

The array of slivers is transferred using vacuum from the second pair of belts to the substrate having adhesive material applied to a surface of the substrate and bringing a face of each sliver into contact with a portion of the adhesive material. Preferably, the adhesive is optical adhesive and may be stamped on the substrate in strips. Each sliver is released by ceasing the vacuum to provide the array of slivers located in situ on the substrate and adhering to the substrate. The adhesive then hardens; this may be done by ultraviolet (UV) curing the adhesive material. Electrically conductive material is applied to electrically connect two or more of the slivers in the array adhering to the substrate.

The foregoing embodiments of the invention may be practiced with slivers that are 1 mm wide and approximately 110 mm long, for example. In other embodiments, the slivers may be 70 mm or 120 mm in length. The slivers may be used to implement solar cells. The slivers may be separate one from another by gaps of 80 μ m to 100 μ m. In the first pair of belts, the spacing between castellations may be 3 mm where the slivers are 1 mm wide. Further, slivers are separated by empty spaces on the belt up to 10 mm. The second pair of belts may have adjacent castellations separated by 3 mm. The pitch may be changed to accord with changes in the dimensions of the slivers or other processing requirements. The lifter/referencer may have a spacing of 1.4 mm between adjacent castellations and can be used to adjust the position of the slivers vis-à-vis to within a tolerance of approximately 0.01 mm or thereabout. While specific dimensions have disclosed for the slivers, belts and other assemblies, it will be appreciated by those skilled in the art that adjustments and variations in dimensions dependent upon the application without departing from the scope and spirit of the invention.

Any of a number of other techniques for electrically interconnecting slivers may be applied beside the method of forming pads on the substrate prior to adhesion of the slivers to the substrate. Further in the embodiment shown in Figs. 29 to 31, dog-bone shaped pads may be used to interconnect rows or blocks of slivers on the substrate.

The embodiments of the invention advantageously utilize vacuum to snap slivers from the wafer. The vacuum concept is well suited for engagement of the sliver on the wafer and to snap the sliver from the wafer without damaging the fragile sliver. The slivers can be inconsistent on the wafer – some are convex, some are concave, some have an “S” shape, some are broken and others may be stuck together with a second sliver.

The method of separating slivers is characterized by:

1. Engaging a sliver by its relatively large and easier to find bottom face.
2. Not relying on precise positioning such as trying to find the small and position variable gap between slivers.
3. Having a generous depth of field of engagement, i.e. engages the sliver even if the sliver is out of position vertically by 1mm, for example.

4. Not dependent on whether the bottom sliver is joined to the one above that sliver.

5. Not dependent upon whether the bottom sliver is already broken, but is robust in a production environment.

5

Alternative mechanisms to apply vacuum to the sliver are:

- a. Use a indexing vacuum drum to which the wafer vertically reciprocates and after engaging a sliver onto the vacuum drum, the vacuum drum and sliver rotate say 10 degrees and be ready for engagement of another sliver. The slivers can be engaged at 12 o'clock and released say at 6 o'clock. This concept has advantages of a rigid indexing drum, ability to release at multiple positions (say 4 o'clock, 6 o'clock and 8 o'clock for grading slivers into multiple grades), but may limit the space to implement a sliver testing function.
- 10 b. Use a reciprocating set of vacuum cups or pads to engage the sliver on a fixed (or gross indexing) wafer. This works with either the twin timing belt or the vacuum drum concept, but may have a slower cycle time.
- 15 c. Use a vacuum cup or pad on a manipulator (or robot) and pick each sliver and place the sliver either directly on the assembly substrate, a testing station, or into a magazine or temporary holding station. The wafer can be orientated "U" clamp upwards. This method may be slow but can use multiple pickup heads or robots.
- 20

As yet another alternative, sticky carrier strip(s) may be used onto which the wafer reciprocates leaving a sliver behind on the strip(s) each time. The sticky strips need some vertical compliance as the position of each sliver's bottom face can vary if the sliver is not straight and flat.

The embodiments of the invention advantageously maintain the orientation of the slivers as removed from the wafer throughout the relevant processing through to assembly of the array on the substrate.

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In solar cell applications, the embodiments advantageously reduce the semiconductor (silicon) per watt of output produced.

In the foregoing manner, a number of methods, apparatuses, and systems have
5 been disclosed for separating elongated semiconductor strips from a wafer of
semiconductor material, assembling a plurality of elongated semiconductor strips
separated from a wafer of semiconductor material into an array of the strips, and
assembling an array of elongated semiconductor strips on a substrate. While only a small
number of embodiments have been disclosed, it will be apparent to those skilled in the art
10 in the light of this disclosure that numerous changes and substitutions may be made
without departing from the scope and spirit of the invention.

We claim:

1. A method of separating elongated semiconductor strips from a wafer of semiconductor material, said method comprising the steps of:
 - 5 providing a plurality of elongated semiconductor strips formed in a wafer in a substantially parallel manner with respect to each other, said wafer having a substantially planar surface and a thickness dimension at a right angle to the substantially planar surface and a frame portion at opposite ends of said semiconductor strips connecting said strips to said wafer, said semiconductor strips each having a width at least substantially
 - 10 equal to the wafer thickness and a thickness dimension of said strip less than said width, a face of at least one of elongated semiconductor strips lengthwise forming an edge of said wafer or being nearest adjacent said edge;
 - applying vacuum to said elongated semiconductor strip forming said edge or being adjacent to said edge; and
 - 15 displacing said wafer and a source of said vacuum relative to each other a predetermined distance to separate said elongated semiconductor strip having vacuum applied to said elongated semiconductor strip from said wafer.
2. The method according to claim 1, further comprising the steps of:
 - 20 at least reducing said vacuum applied to said separated, elongated semiconductor strip; and
 - displacing said separated, elongated semiconductor strip and said source of said vacuum relative to each other.
3. The method according to claim 1, wherein the step of at least reducing said vacuum comprises terminating said vacuum.
4. The method according to claim 1, further comprising the step of:
 - moving said wafer so that said elongated semiconductor strip is in close proximity
 - 30 to said source of said vacuum.
5. The method according to claim 1, further comprising the step of:

moving said source of said vacuum relative to said wafer so that said source of said vacuum is in close proximity to said elongated semiconductor strip.

6. The method according to any one of claims 1 to 5, wherein said steps are repeatedly performed to separate two or more of said plurality of said elongated semiconductor strips from said wafer.

7. The method according to any one of claims 1 to 6, wherein said source of said vacuum has a body with at least one cavity formed therein for providing said applied vacuum, said cavity adjacent said elongated semiconductor strip being substantially the same in size as or smaller than a dimension of a face of said elongated semiconductor strip.

8. The method according to any one of claims 1 to 7, further comprising the step of:
forming weak points in portions of said wafer adjacent opposite ends of said elongated semiconductor strips to facilitate separation of said elongated semiconductor strip from said wafer.

9. The method according to any one of claims 1 to 8, wherein said wafer is single crystal silicon or multicrystalline silicon.

10. An apparatus for separating elongated semiconductor strips from a wafer of semiconductor material, said apparatus comprising:
means for holding a wafer having a plurality of elongated semiconductor strips formed in a substantially parallel manner with respect to each other in said wafer, said wafer having a substantially planar surface and a thickness dimension at a right angle to the substantially planar surface and a frame portion at opposite ends of said semiconductor strips connecting said strips to said wafer, said semiconductor strips each having a width at least substantially equal to the wafer thickness and a thickness dimension of said strip less than said width, at least one of elongated semiconductor strips lengthwise forming an edge of said wafer or being nearest adjacent said edge;

a vacuum source to apply vacuum to said face of said elongated semiconductor strip forming said edge or being adjacent to said edge; and

means for displacing said wafer and said source of said vacuum relative to each other a predetermined distance to separate said elongated semiconductor strip having
5 vacuum applied to said elongated semiconductor strip from said wafer.

11. The apparatus according to claim 10, where said vacuum applied to said separated, elongated semiconductor strip is at least reduced, and further comprising means for displacing said separated, elongated semiconductor strip and said source of said
10 vacuum relative to each other.

12. The apparatus according to claim 10, wherein at least reducing said vacuum comprises terminating said vacuum.

13. The apparatus according to claim 10, further comprising:
means for moving said wafer so that said elongated semiconductor strip is in close
proximity to said source of said vacuum.

14. The apparatus according to claim 10, further comprising:
20 means for moving said source of said vacuum relative to said wafer so that said source of said vacuum is in close proximity to said elongated semiconductor strip.

15. The apparatus according to any one of claims 10 to 14, further comprising means for controlling operation of at least said holding means, said source of said
25 vacuum, and said displacing means to repeatedly perform operations to separate two or more of said plurality of said elongated semiconductor strips from said wafer.

16. The apparatus according to any one of claims 10 to 15, wherein said source of said vacuum has a body with at least one cavity formed therein for providing
30 said applied vacuum, said cavity adjacent said face of said elongated semiconductor strip being substantially the same in size as or smaller than a dimension of a face of said elongated semiconductor strip.

17. The apparatus according to any one of claims 10 to 16, further comprising:
means for forming weak points in portions of said wafer adjacent opposite ends of
said elongated semiconductor strips to facilitate separation of said elongated
5 semiconductor strip from said wafer.

18. The apparatus according to any one of claims 10 to 17, wherein said wafer
is single crystal silicon or multicrystalline silicon.

10 19. A method of assembling a plurality of elongated semiconductor strips
separated from a wafer of semiconductor material into an array of said strips, said method
comprising the steps of:

receiving at a predetermined position of at least one belt one of said elongated
semiconductor strips oriented lengthwise across said belt;

15 moving said belt in a given direction by a predetermined distance greater than the
width of said elongated semiconductor strip; and

repeating said receiving and moving steps until all of said elongated
semiconductor strips have been processed.

20 20. The method according to claim 19, wherein a vacuum source applies a
vacuum to said elongated semiconductor strip and is used to deliver said elongated
semiconductor strip at said predetermined position, and said predetermined distance is
relative to said vacuum source.

25 21. The method according to claim 19 or 20, wherein said belt is made of a
tape-like fabric and has adhesive on a surface upon which said elongated semiconductor
strip is received.

22. The method according to claim 21, wherein said belt is made of mylar.

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23. The method according to claim 19 or 20, wherein said belt is castellated
and has a distance between adjacent castellations substantially wider than the width of

said elongated semiconductor strip, said predetermined position located between castellations on said belt and each elongated semiconductor strip is located between two adjacent castellations on said belt.

- 5 24. The method according to claim 23, further comprising the steps of:
transferring each elongated semiconductor strip from said belt to at least one
further belt located adjacent thereto, said at least one further belt having castellations with
a distance between adjacent castellations greater than the width of an elongated
semiconductor strip but substantially less than adjacent castellations of said belt that
10 received said elongated semiconductor strip;
moving said further belt in a given direction by a predetermined distance greater
than the width of said elongated semiconductor strip; and
repeating said transferring and moving steps until at least a portion of said
elongated semiconductor strips have been processed forming said array of strips.

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25. The method according to claim 24, wherein said transferring step
comprises applying vacuum to each elongated semiconductor strip during movement of
said further belt.

- 20 26. The method according to any one of claims 19 to 23, wherein said at least
one belt comprises two parallel belts.

27. The method according to claim 24 or 25, wherein said at least one belt
comprises two parallel belts and said at least one further belt comprises two further
25 parallel belts.

28. An apparatus for assembling a plurality of elongated semiconductor strips
separated from a wafer of semiconductor material into an array of said strips, said
apparatus comprising:
30 at least one belt receiving at predetermined positions one of said elongated
semiconductor strips oriented lengthwise across said belt;

a motor moving said belt in a given direction by a predetermined distance greater than the width of said elongated semiconductor strip; and

a controller coupled to said motor repeating said receiving and moving operations until all of said elongated semiconductor strips have been processed.

5

29. The apparatus according to claim 28, further comprises a vacuum source applying a vacuum to said elongated semiconductor strip and used to deliver said elongated semiconductor strip at said predetermined positions, said predetermined distance being relative to said vacuum source.

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30. The apparatus according to claim 28 or 29, wherein said belt is made of a tape-like fabric and has adhesive on a surface upon which said elongated semiconductor strip is received.

15

31. The apparatus according to claim 29, wherein said belt is made of mylar.

20

32. The apparatus according to claim 28 or 29, wherein said belt is castellated and has a distance between adjacent castellations substantially wider than the width of said elongated semiconductor strip, said predetermined position located between castellations on each belt and each elongated semiconductor strip located between two adjacent castellations on said belt.

25

33. The apparatus according to claim 29, further comprising:
at least one further belt located adjacent to said at least one belt;
means for transferring each elongated semiconductor strip from said belt to said further belt, said at least one further belt having castellations with a distance between adjacent castellations greater than the width of an elongated semiconductor strip but substantially less than adjacent castellations of said belt that received said elongated semiconductor strip; and

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a motor moving said further belt in a given direction by a predetermined distance greater than the width of said elongated semiconductor strip;

wherein said controller repeats said transferring and moving operations until at least a portion of said elongated semiconductor strips have been processed forming said array of strips.

5 34. The apparatus according to claim 33, wherein said transferring means comprises a second vacuum source applying vacuum to each elongated semiconductor strip during movement of said further belt.

10 35. The apparatus according to any one of claims 28 to 32, wherein said at least one belt comprises two parallel belts.

15 36. The apparatus according to claim 33 or 34, wherein said at least one belt comprises two parallel belts and said at least one further belt comprises two further parallel belts.

20 37. A method of assembling an array of elongated semiconductor strips on a substrate, said method comprising the steps of:
 applying adhesive material on said substrate in a predetermined manner;
 applying vacuum to each one of said elongated semiconductor strips to maintain
 said strips in said array, said array being a predefined arrangement of said strips;
 transferring said array of elongated semiconductor strips to said substrate and
 bringing a face of each elongated semiconductor strip into contact with a portion of said
 adhesive material; and
 ceasing said vacuum applied to each elongated semiconductor strip to provide said
25 array of elongated semiconductor strips located in situ on said substrate and adhering to
 said substrate.

30 38. The method according to claim 37, further comprising the step of applying electrically conductive material to said substrate to electrically connect two or more of said elongated semiconductor strips in said array adhering to said substrate.

39. The method according to claim 38, wherein said applying step comprises printing pads of said electrically conductive material on said substrate.

40. The method according to claim 38, wherein said adhesive material is applied on said substrate in elongated strips.

41. An apparatus for assembling an array of elongated semiconductor strips on a substrate, said apparatus comprising the steps of:

means for applying adhesive material on said substrate in a predetermined manner;

a vacuum source applying vacuum to each one of said elongated semiconductor strips to maintain said strips in said array, said array being a predefined arrangement of said strips; and

means for transferring said array of elongated semiconductor strips to said substrate and bringing a face of each elongated semiconductor strip into contact with a portion of said adhesive material;

wherein said vacuum source ceases said vacuum applied to each elongated semiconductor strip to provide said array of elongated semiconductor strips located in situ on said substrate and adhering to said substrate.

42. The apparatus according to claim 41, further comprising means for applying electrically conductive material to said substrate to electrically connect two or more of said elongated semiconductor strips in said array adhering to said substrate.

43. The apparatus according to claim 42, wherein said applying means comprises a printer printing pads of said electrically conductive material on said substrate.

44. The apparatus according to claim 42, wherein said adhesive material is applied on said substrate in elongated strips.

45. A method of assembling an array of elongated semiconductor strips on a substrate, said elongated semiconductor strips formed in a wafer in a substantially parallel

manner with respect to each other, said wafer having a substantially planar surface and a thickness dimension at a right angle to the substantially planar surface and a frame portion at opposite ends of said semiconductor strips connecting said strips to said wafer, said method comprising the steps of:

- 5 separating an elongated semiconductor strip from said wafer using vacuum applied to said elongated semiconductor strip forming an edge or being adjacent to an edge of said wafer;
- displacing said wafer from a source of said vacuum relative by a predetermined distance;
- 10 receiving on at least one first belt said elongated semiconductor strip oriented lengthwise across said belt;
- moving said belt in a given direction by a predetermined distance greater than the width of said elongated semiconductor strip;
- repeating the foregoing steps until all of said elongated semiconductor strips have
- 15 been processed.

46. The method according to claim 45, wherein said at least one first belt is made of a tape-like fabric and has adhesive on a surface upon which said elongated semiconductor strip is received.

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47. The method according to claim 45, further comprising the step of displacing said separated, elongated semiconductor strip and said source of said vacuum relative to each other.

25 48. The method according to claim 45 or 47, wherein said at least one first belt is castellated and has a distance between adjacent castellations substantially wider than the width of said elongated semiconductor strip, and further comprising the steps of:

 transferring each elongated semiconductor strip from said first belt to at least one second belt using vacuum, said second belt having castellations with a distance between

30 adjacent castellations greater than the width of an elongated semiconductor strip but substantially less than adjacent castellations of said first belt;

moving said at least one second belt in a given direction by a predetermined distance greater than the width of said elongated semiconductor strip; and

repeating said transferring and moving steps until at least a portion of said elongated semiconductor strips have been processed forming said array of strips.

5

49. The method according to claim 48, further comprising the steps of:

transferring said array of elongated semiconductor strips using vacuum to said substrate having adhesive material applied to a surface of said substrate and bringing a face of each elongated semiconductor strip into contact with a portion of said adhesive material; and

10

releasing each elongated semiconductor strip by ceasing said vacuum to provide said array of elongated semiconductor strips located in situ on said substrate and adhering to said substrate.

15

50. The method according to claim 49, wherein said substrate also has electrically conductive material applied to said substrate to electrically connect two or more of said elongated semiconductor strips in said array adhering to said substrate.

51. The method according to any one of claims 45 to 50, wherein said wafer is single crystal silicon or multicrystalline silicon.

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52. The method according to any one of claims 45 to 47, wherein said at least one first belt comprises two parallel belts.

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53. The method according to claim 48 or 49, wherein said at least one first belt comprises two parallel belts and said at least one second belt comprises two further parallel belts.

30

54. A system for assembling an array of elongated semiconductor strips on a substrate, said elongated semiconductor strips formed in a wafer in a substantially parallel manner with respect to each other, said wafer having a substantially planar surface and a thickness dimension at a right angle to the substantially planar surface and a frame

portion at opposite ends of said semiconductor strips connecting said strips to said wafer, said system comprising the steps of:

a vacuum source for separating an elongated semiconductor strip from said wafer using vacuum applied to said elongated semiconductor strip forming an edge or being
5 adjacent to an edge of said wafer;

means for displacing said wafer from a source of said vacuum relative by a predetermined distance;

at least one first belt receiving said elongated semiconductor strip oriented lengthwise across said belt;

10 a motor moving said at least one belt in a given direction by a predetermined distance greater than the width of said elongated semiconductor strip;

a controller repeating the foregoing operations until all of said elongated semiconductor strips have been processed.

15 55. The system according to claim 54, wherein said at least one first belt is made of a tape-like fabric and has adhesive on a surface upon which said elongated semiconductor strip is received.

20 56. The system according to claim 54, wherein said separated, elongated semiconductor strip and said source of said vacuum can be displaced relative to each other.

25 57. The system according to claim 54 or 56, wherein said at least one first belt is castellated and has a distance between adjacent castellations substantially wider than the width of said elongated semiconductor strip, and further comprising:

at least one second belt having castellations with a distance between adjacent castellations greater than the width of an elongated semiconductor strip but substantially less than adjacent castellations of said at least one first belt

30 means for transferring each elongated semiconductor strip from said at least one first belt to said at least one second belt using vacuum; and

a motor moving said at least one second belt in a given direction by a predetermined distance greater than the width of said elongated semiconductor strip;

said controller repeating said transferring and moving operations until at least a portion of said elongated semiconductor strips have been processed forming said array of strips.

5 58. The system according to claim 57, further comprising:
 means for transferring said array of elongated semiconductor strips using vacuum to said substrate having adhesive material applied to a surface of said substrate and bringing a face of each elongated semiconductor strip into contact with a portion of said adhesive material; and

10 means for releasing each elongated semiconductor strip by ceasing said vacuum to provide said array of elongated semiconductor strips located in situ on said substrate and adhering to said substrate.

 59. The system according to claim 58, wherein said substrate also has
15 electrically conductive material applied to said substrate to electrically connect two or more of said elongated semiconductor strips in said array adhering to said substrate.

 60. The system according to any one of claims 54 to 59, wherein said wafer is
20 single crystal silicon or multicrystalline silicon.

 61. The apparatus according to any one of claims 54 to 56, wherein said at least one first belt comprises two parallel belts.

 62. The apparatus according to claim 57 or 58, wherein said at least one first
25 belt comprises two parallel belts and said at least one second belt comprises two further parallel belts.

 63. A device, comprising:
 a substrate;
30 an array of elongated semiconductor strips separated from a wafer of semiconductor material, said semiconductor strips each having a width substantially equal to the wafer thickness and a thickness dimension of said strip less than the width;

adhesive material deposited between said substrate and a face of each elongated semiconductor strip to adhere said substrate and each elongated semiconductor together, said face having the width of said elongated semiconductor strip as one of its dimensions; and

5 electrically conductive material deposited on said substrate connecting at least two of said elongated semiconductor strips together.

64. The device according to claim 63, wherein each elongated semiconductor strip comprises a sliver photovoltaic solar cell.

10

65. The device according to claim 64, wherein said device is a solar cell module.

15

DATED this Ninth Day of May, 2003

Origin Energy Solar Pty Ltd

Patent Attorneys for the Applicant

SPRUSON & FERGUSON

SEPARATING AND ASSEMBLING SEMICONDUCTOR STRIPS

ABSTRACT

A method and an apparatus for separating elongated semiconductor strips from a
5 wafer of semiconductor material are disclosed. Vacuum is applied to the face of each
elongated semiconductor strip forming an edge of the wafer or being adjacent to the edge.
The wafer and a source of the vacuum are displaced to separate each elongated
semiconductor strip from the wafer. Further, a method and an apparatus for assembling
elongated semiconductor strips separated from a wafer of semiconductor material into an
10 array of the strips are disclosed. Still further, methods, apparatuses, and systems for
assembling an array of elongated semiconductor strips on a substrate are disclosed.

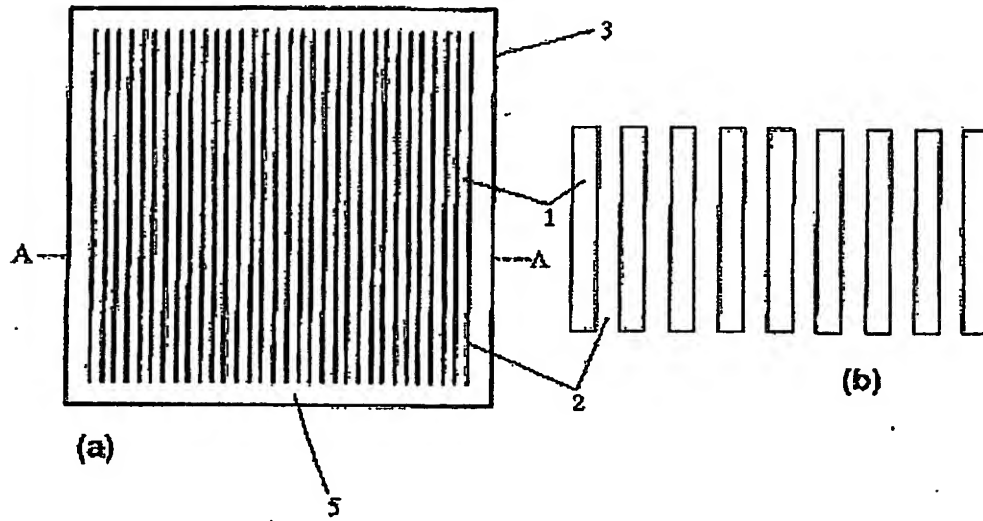


FIG. 1

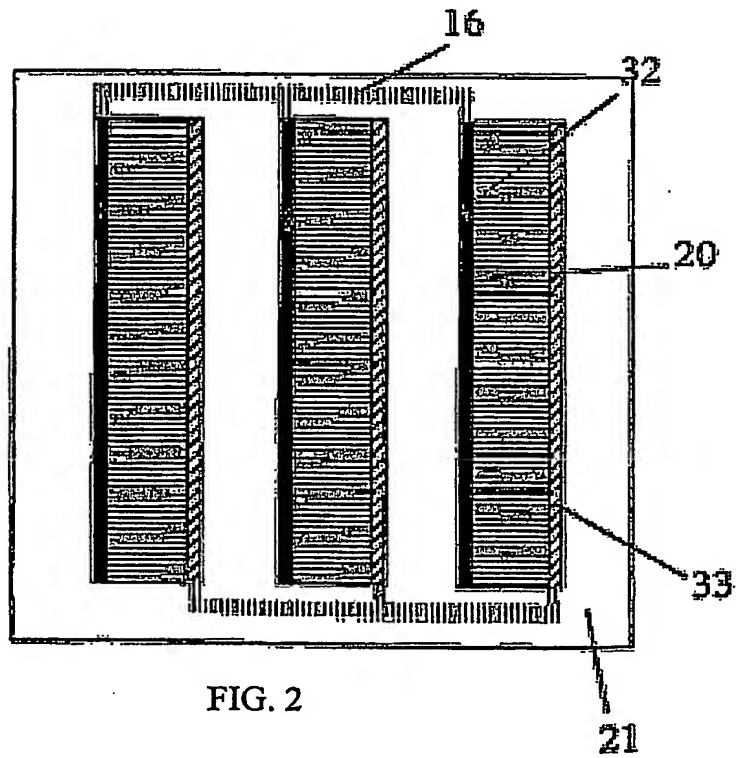


FIG. 2

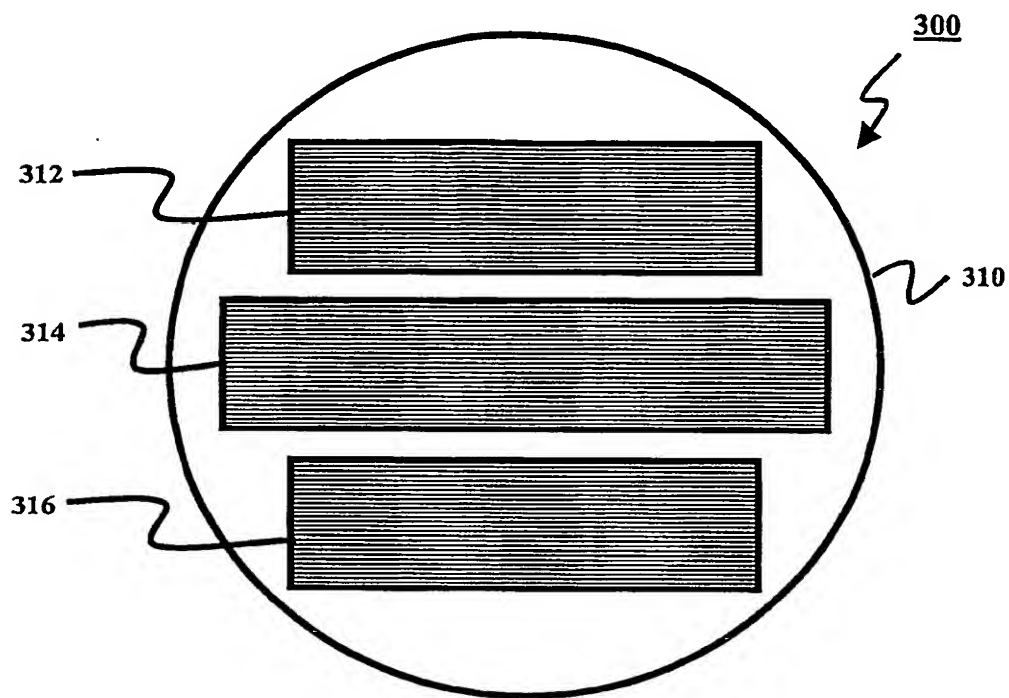


FIG. 3(a)

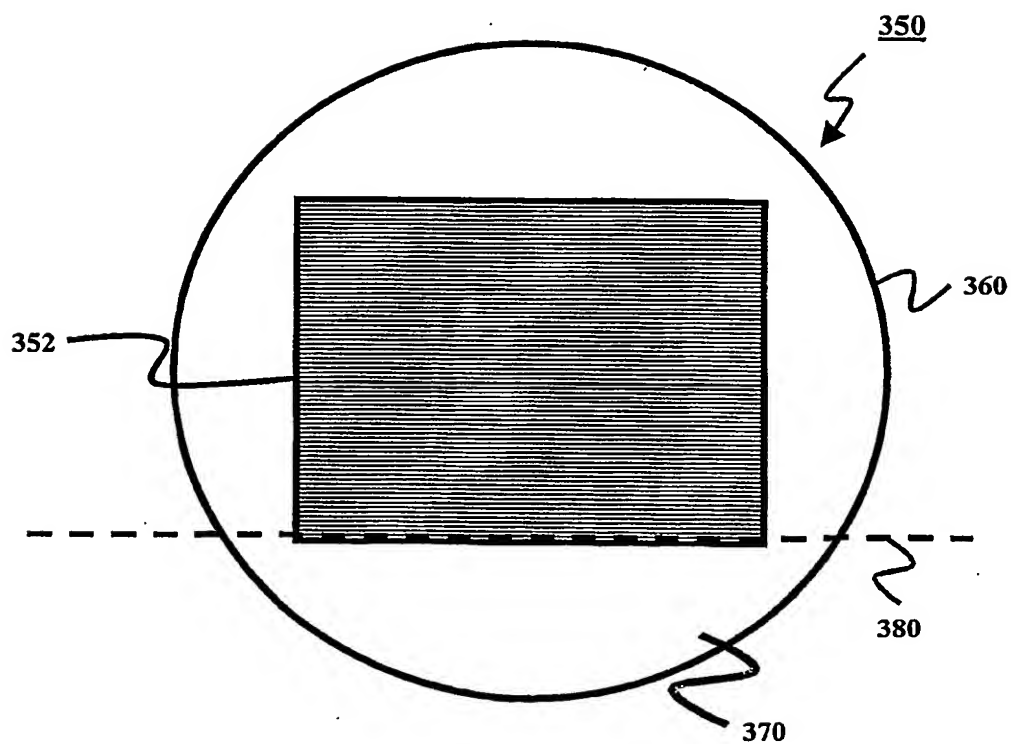
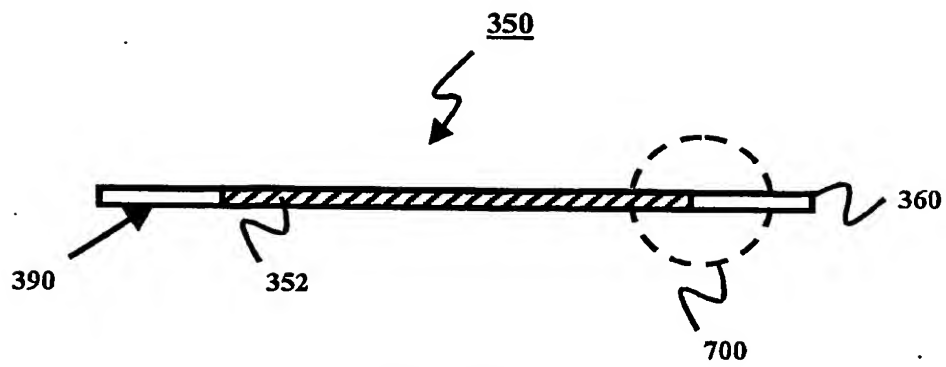
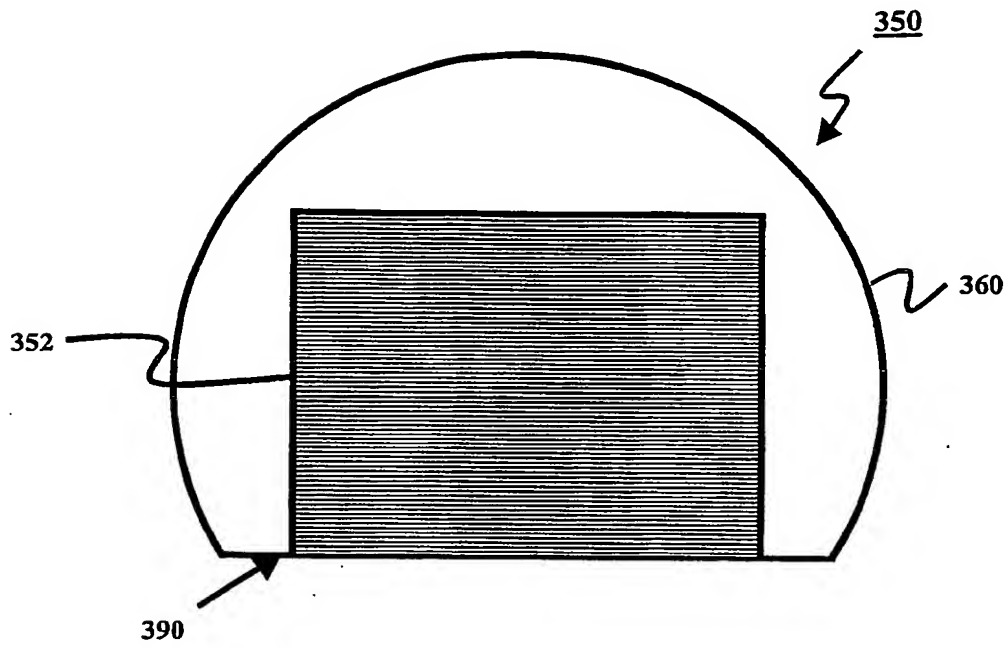


FIG. 3(B)

-3/25-



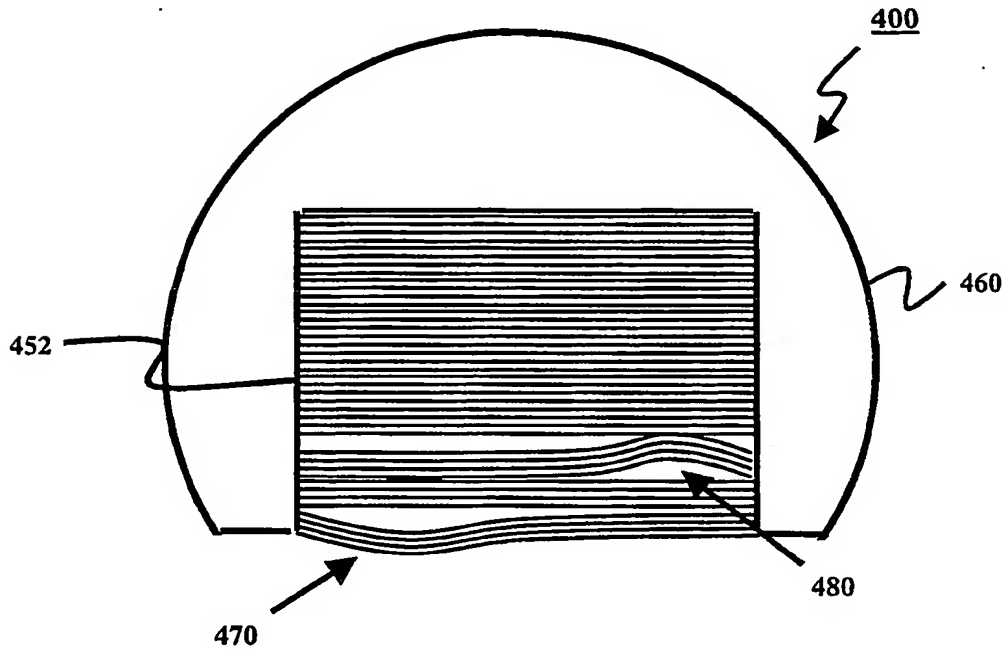


FIG. 4

-5/25-

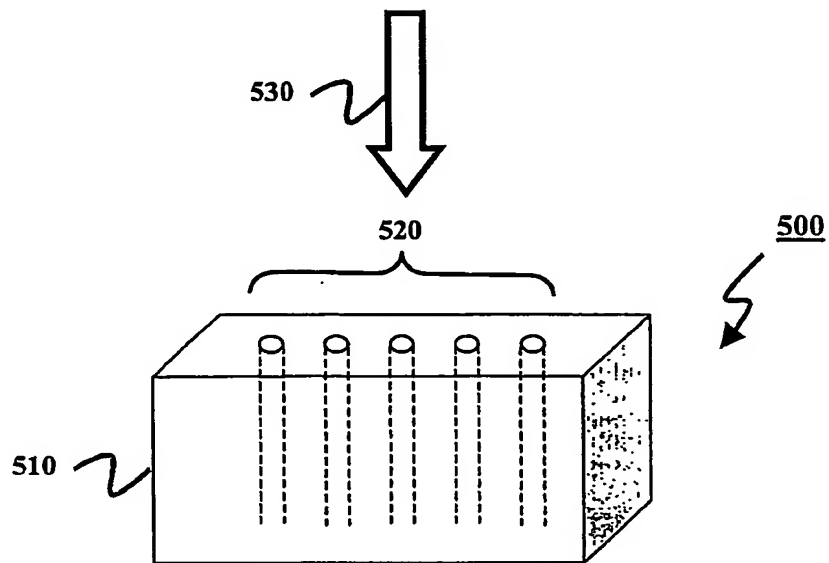


FIG. 5

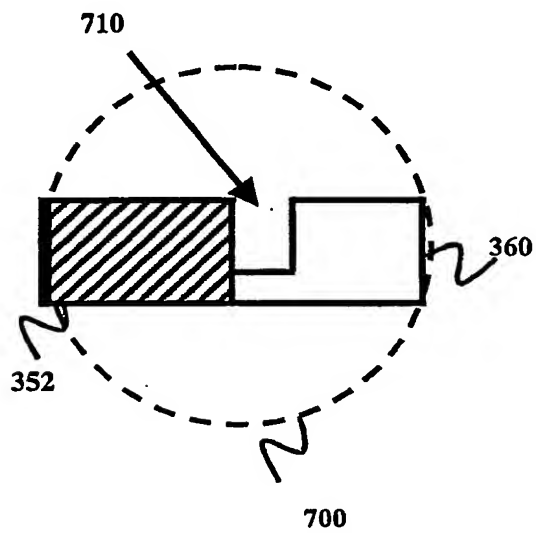


FIG. 7

-6/25-

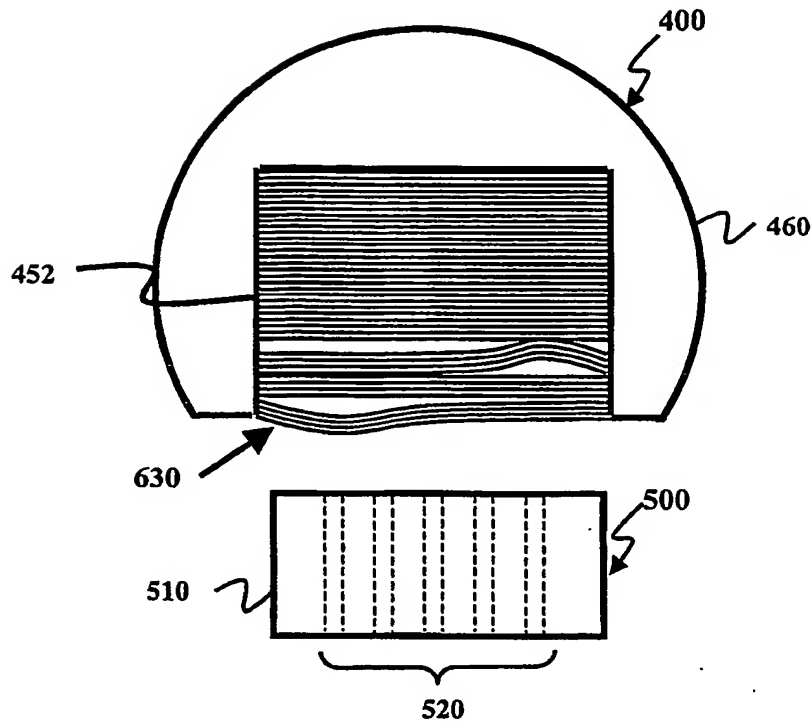


FIG. 6(A)

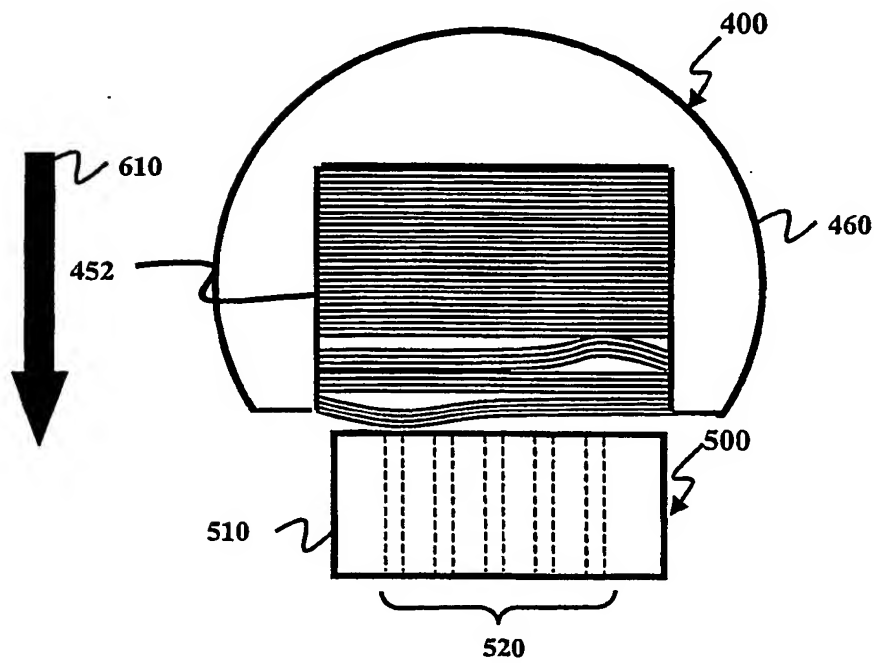


FIG. 6(B)

-7/25-

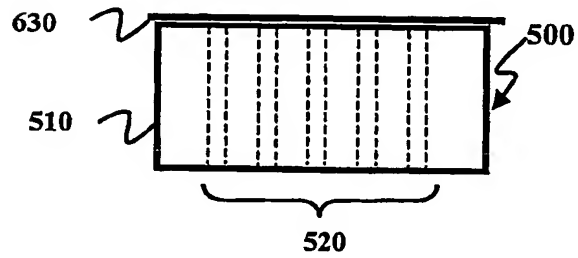
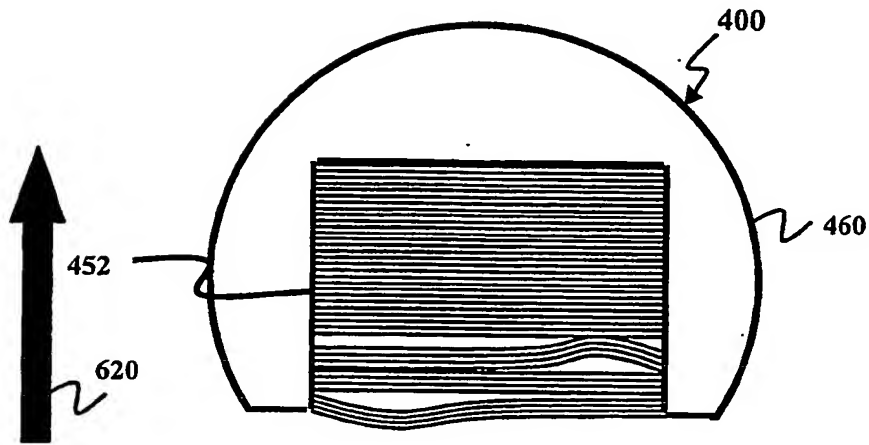


FIG. 6(C)

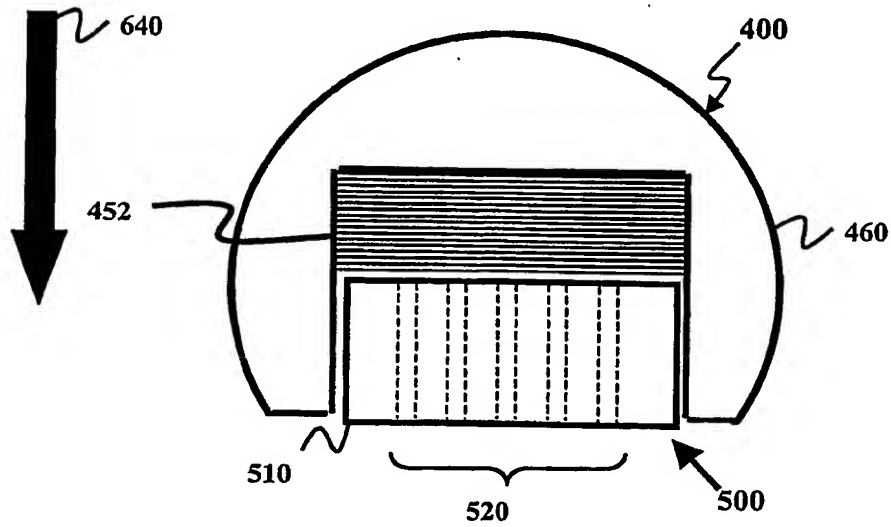


FIG. 6(D)

-8/25-

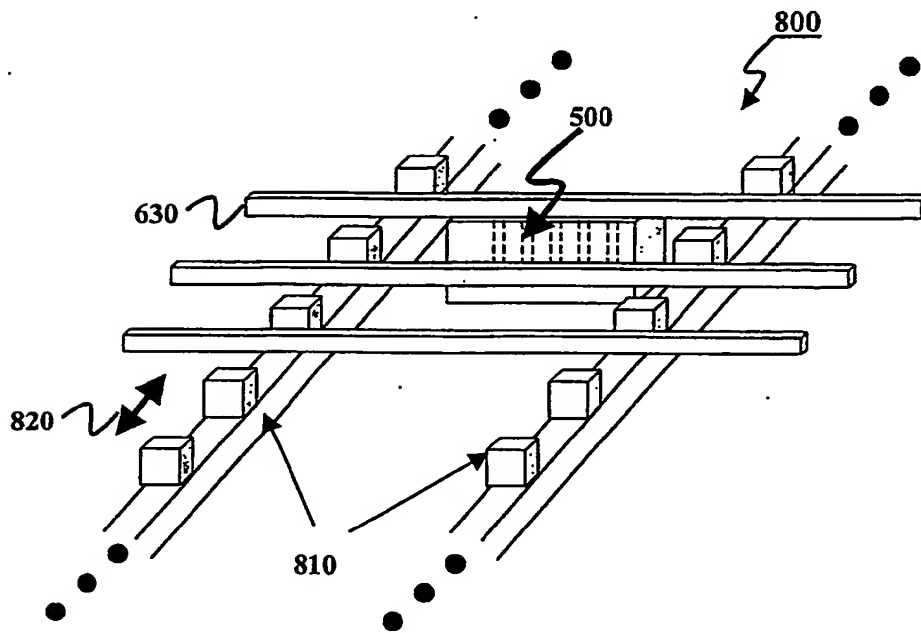


FIG. 8

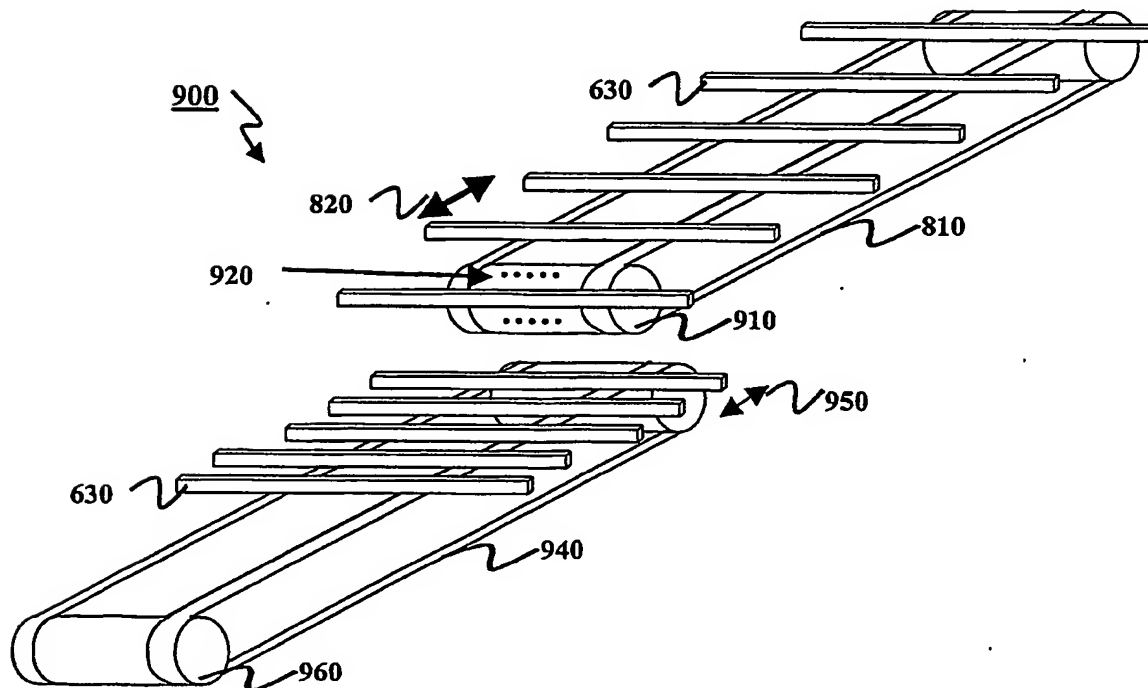


FIG. 9

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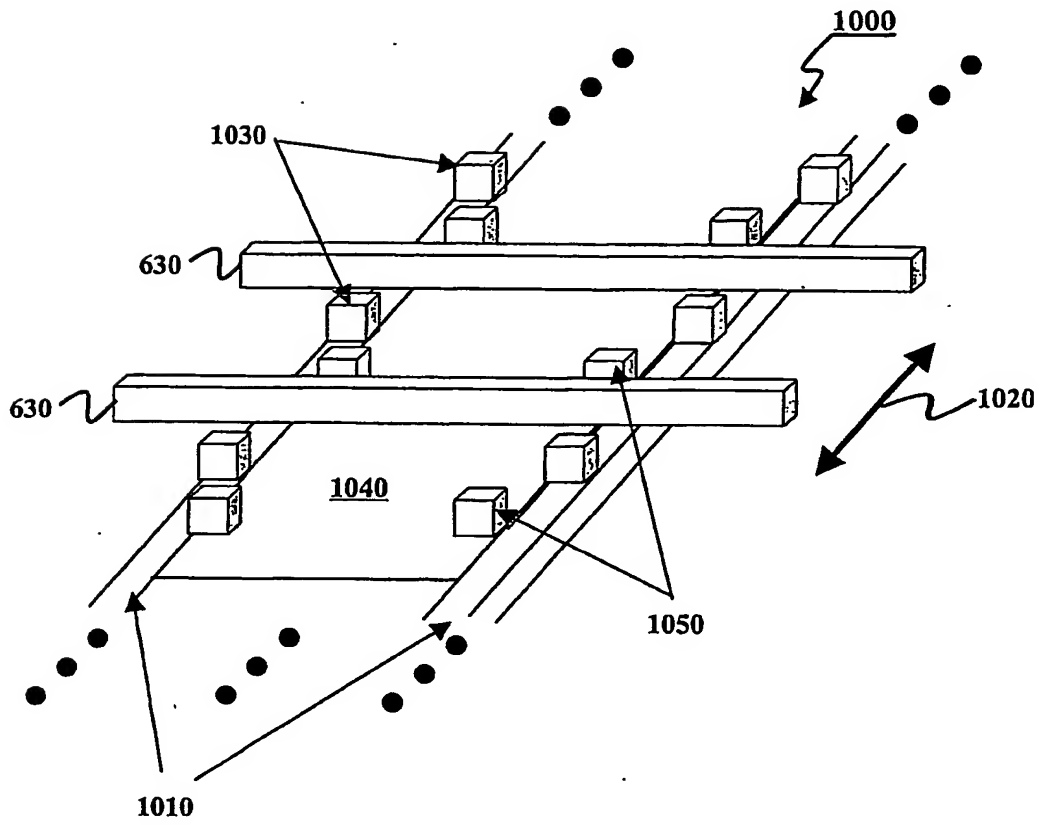


FIG. 10

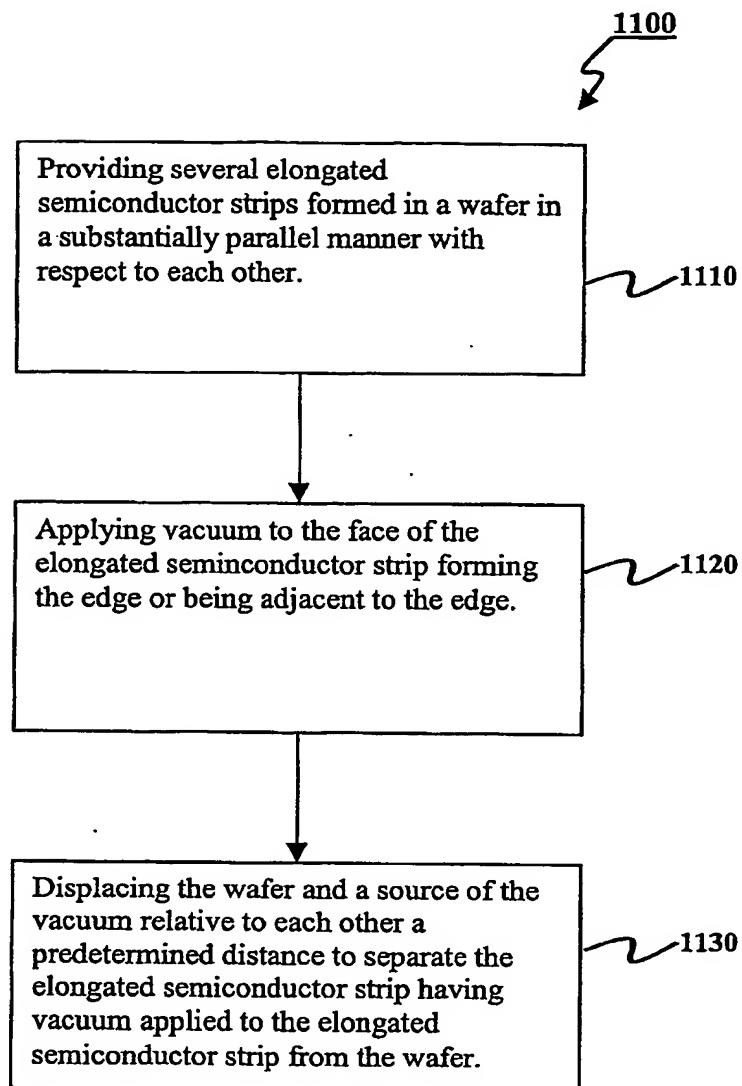


FIG. 11

-11/25-

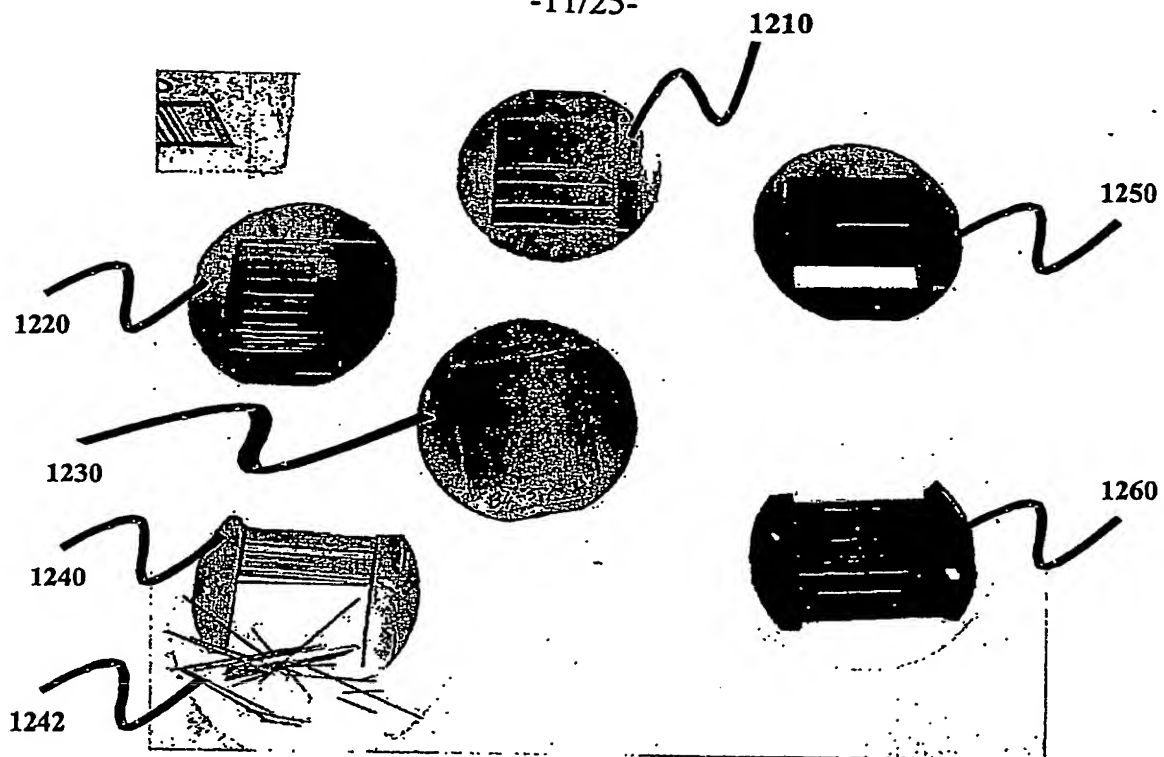


FIG. 12

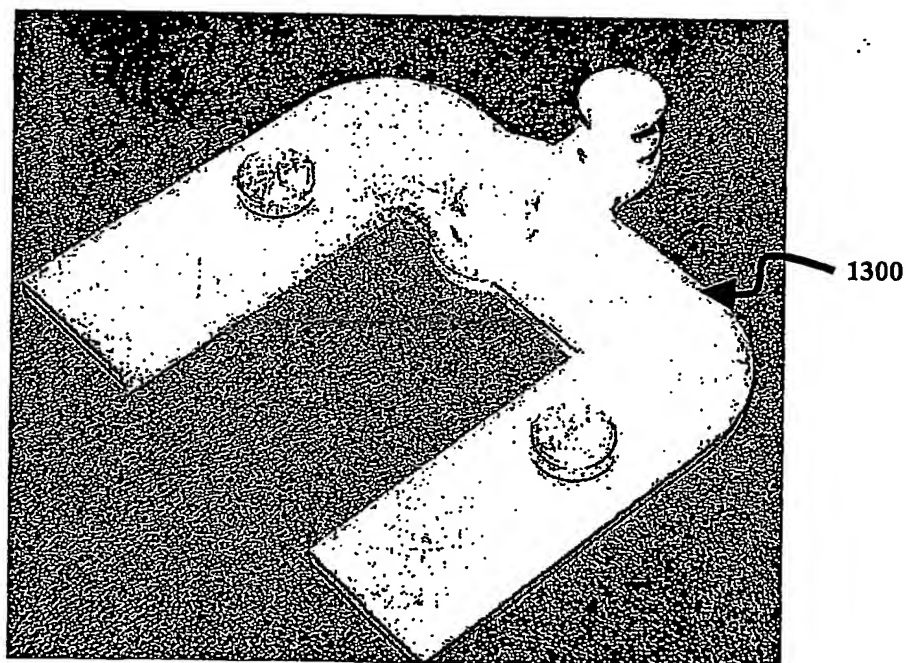


FIG. 13(a)

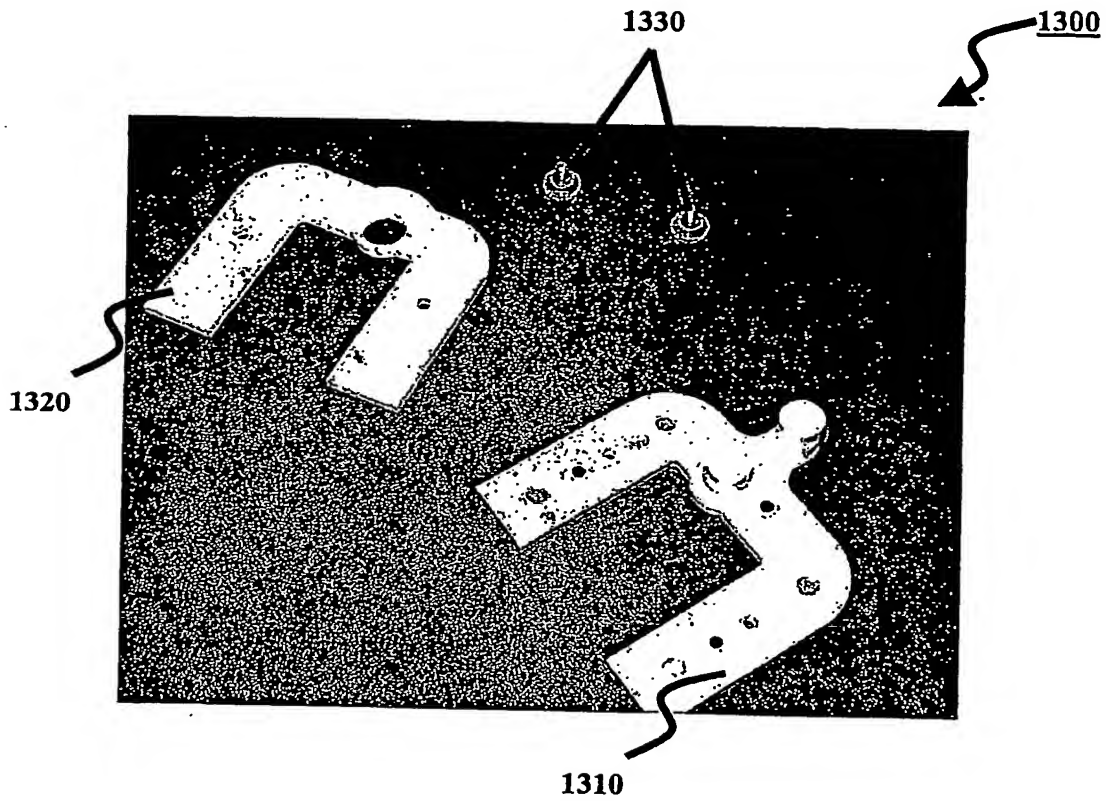


FIG. 13(b)

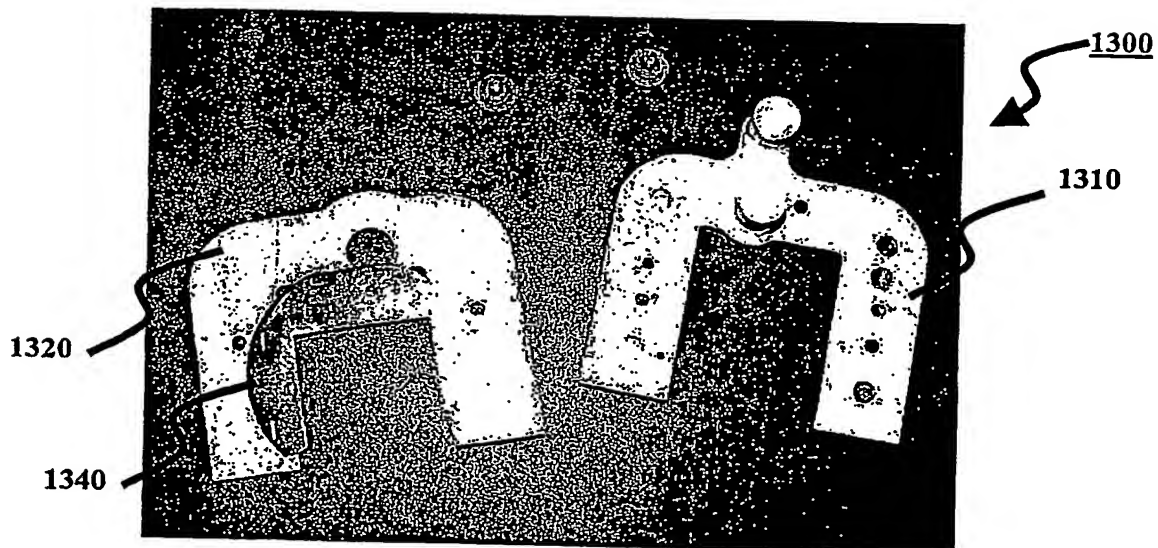


FIG. 13(c)

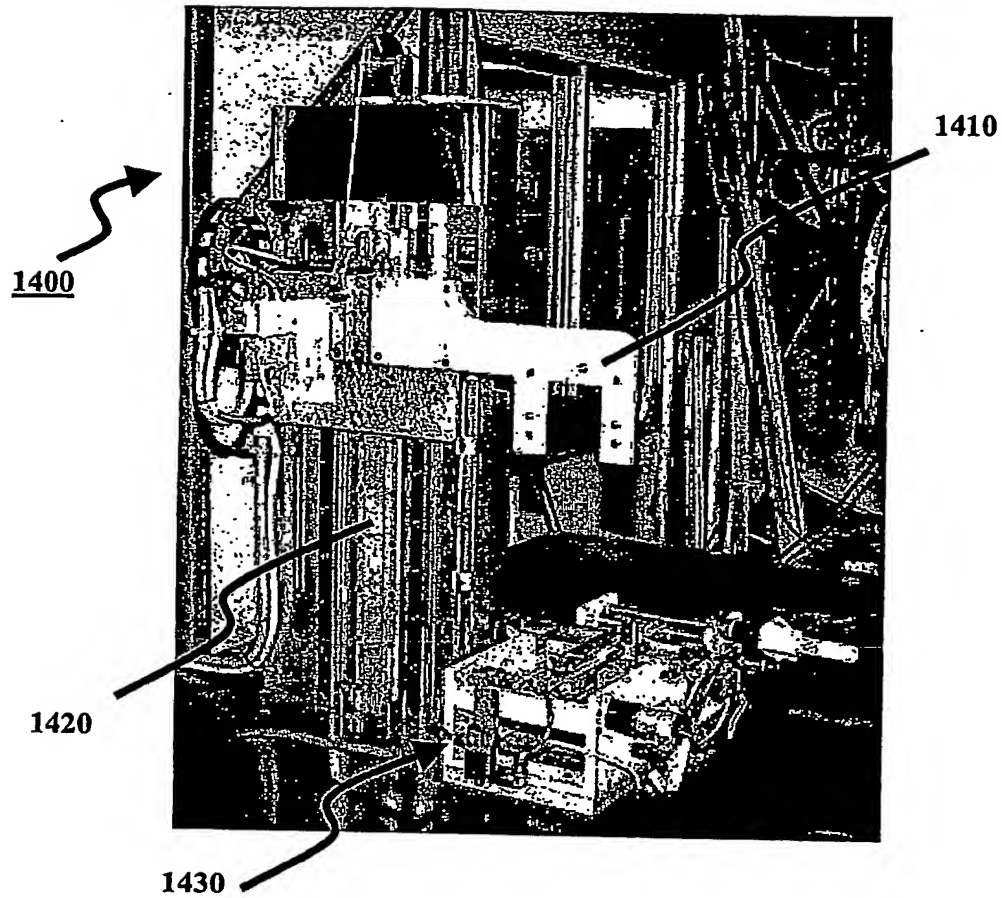


FIG. 14



FIG. 15

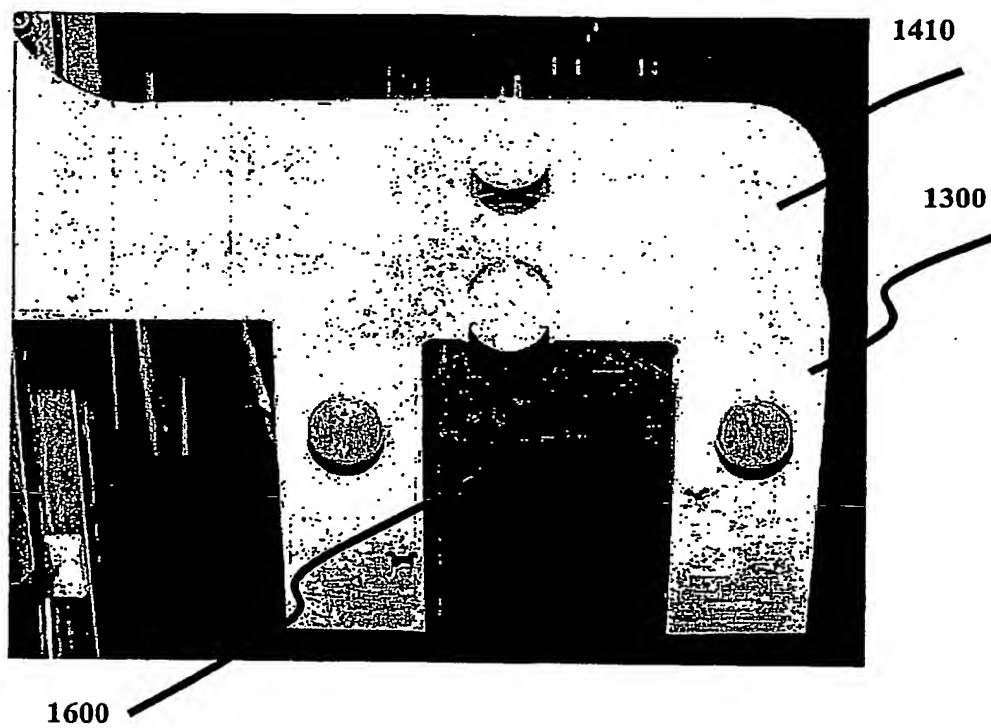
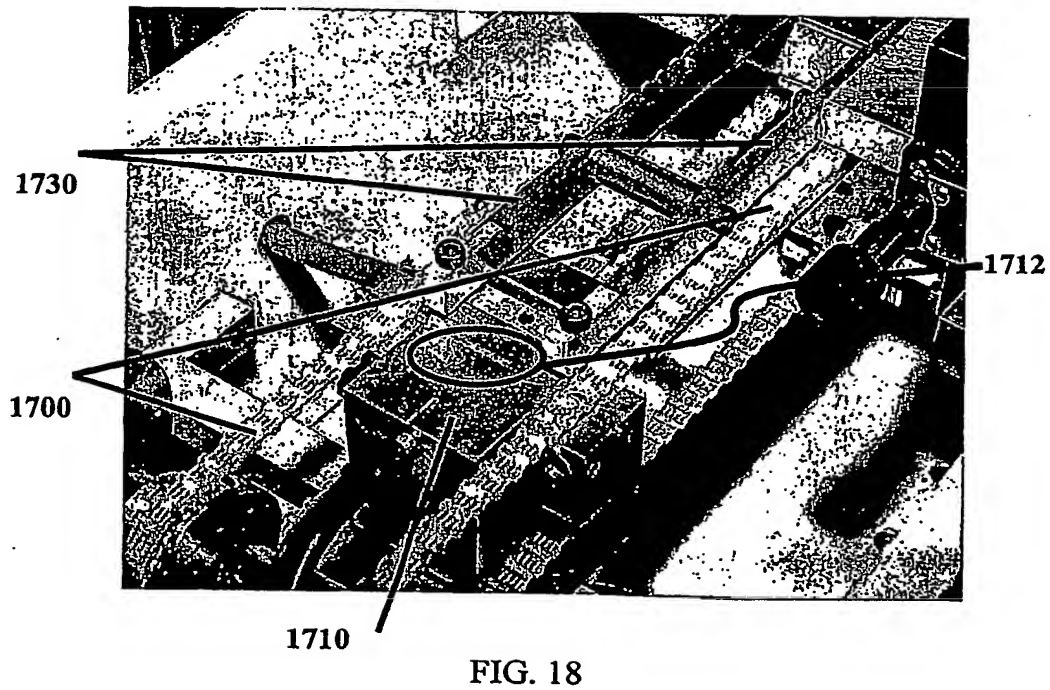
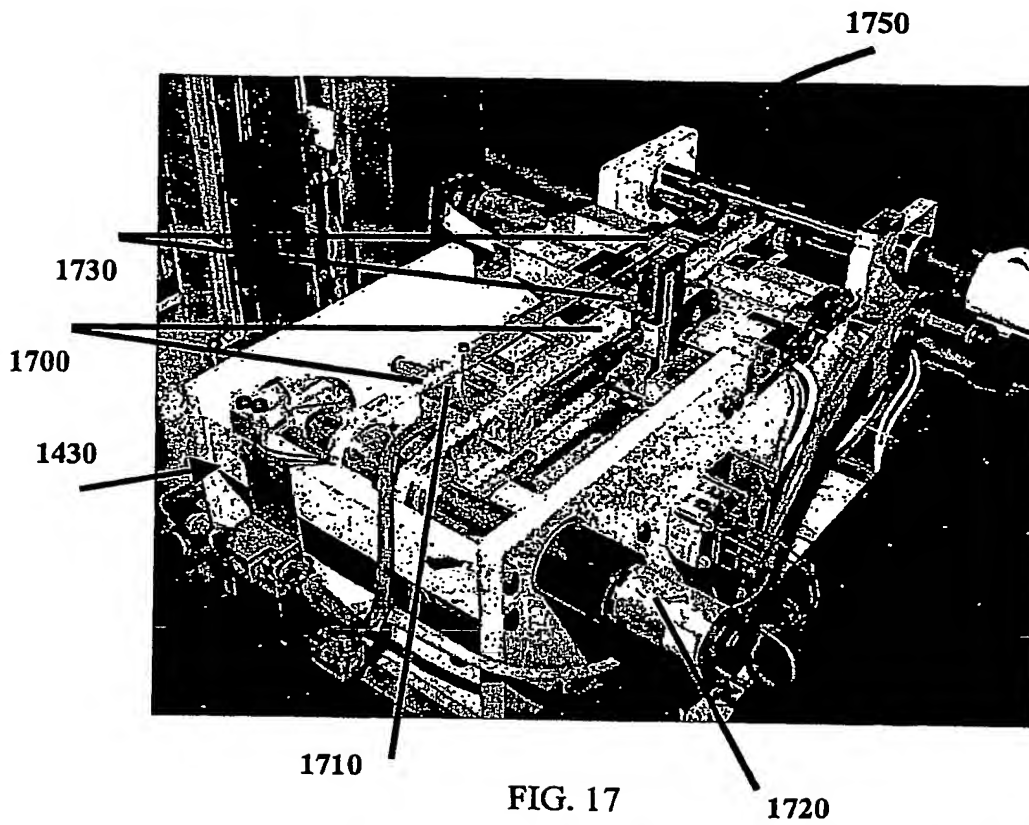


FIG. 16



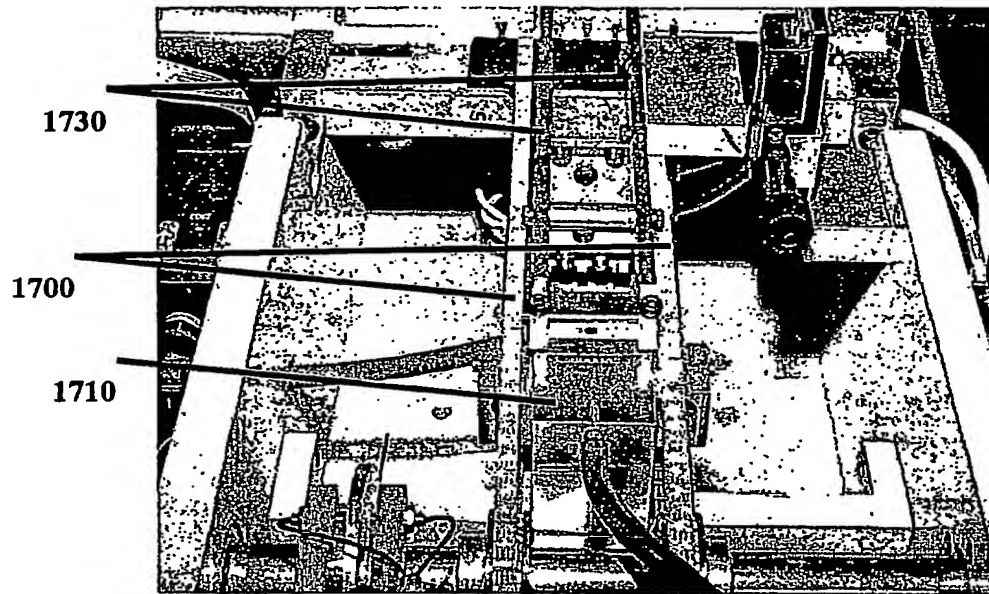


FIG. 19

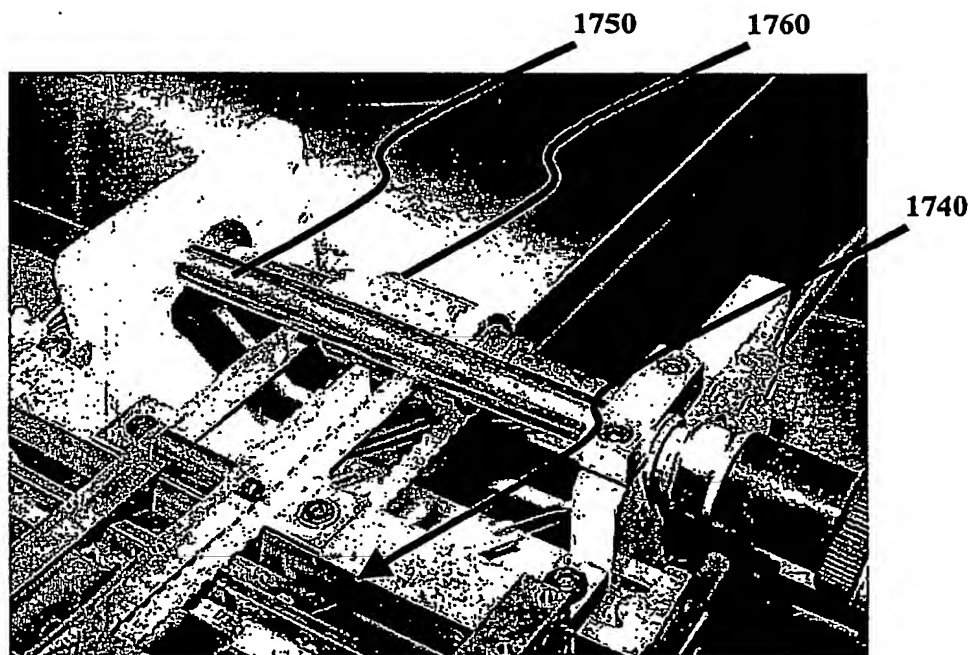
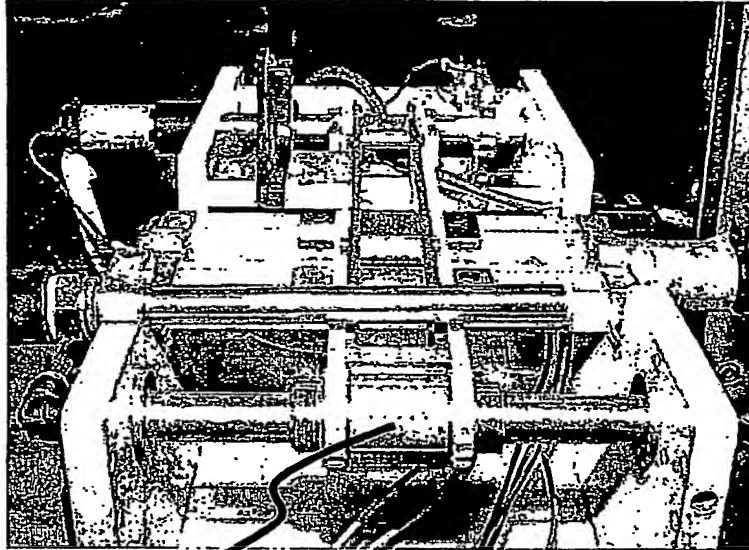


FIG. 20



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FIG. 21

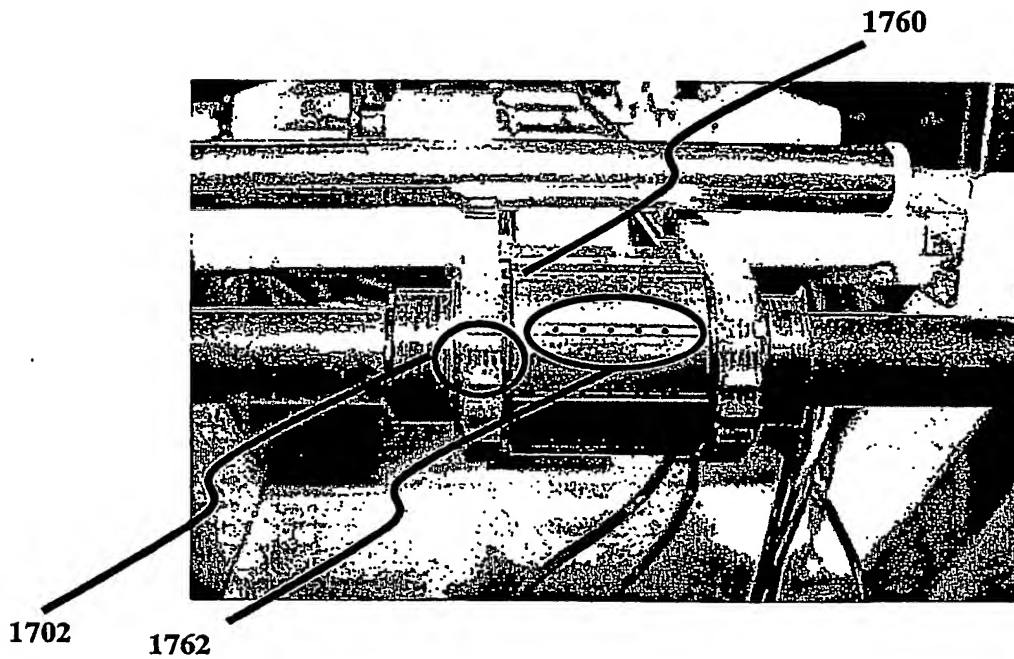


FIG. 22

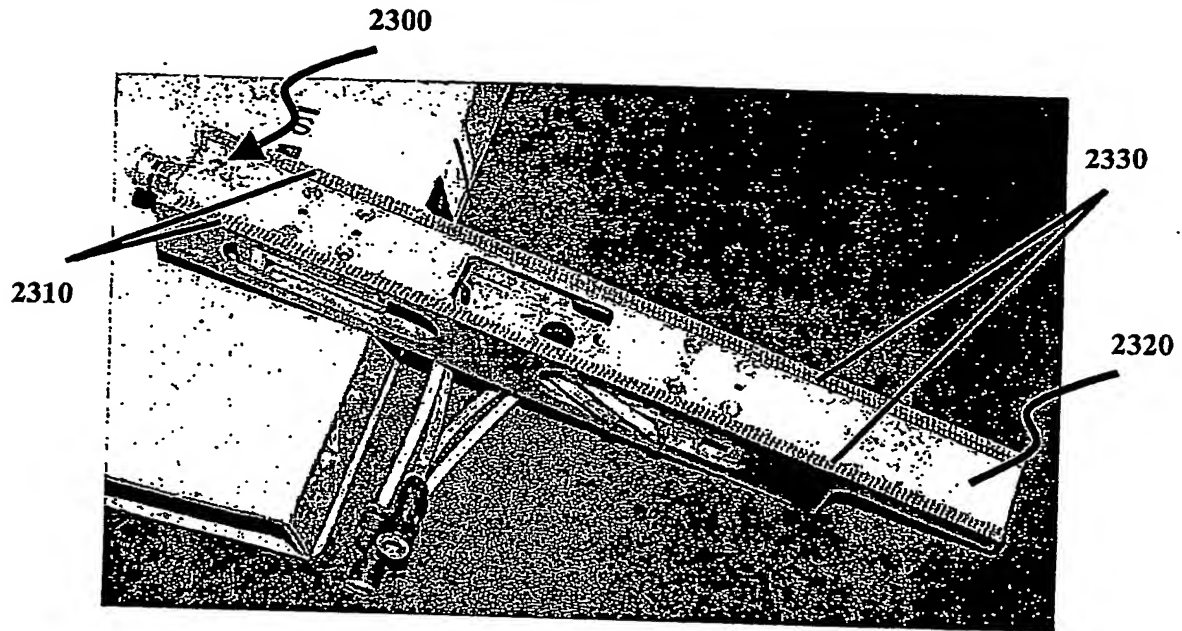


FIG. 23

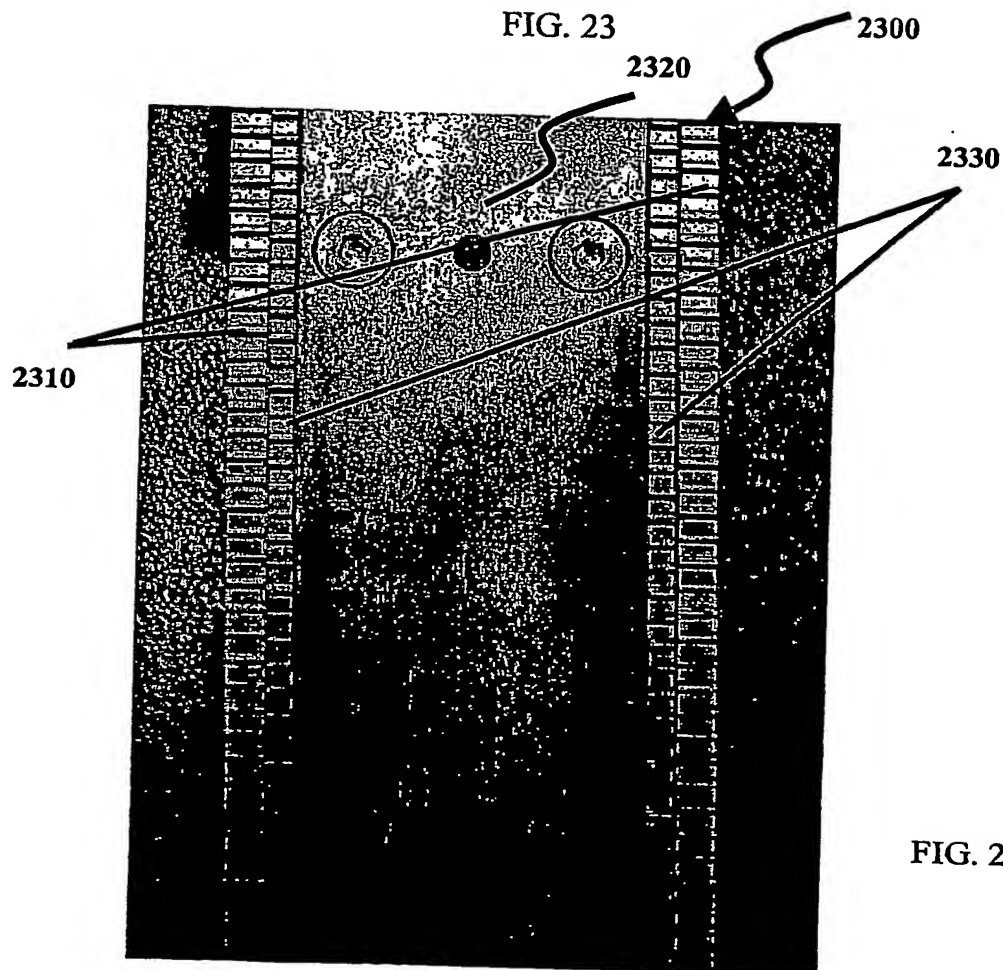


FIG. 24

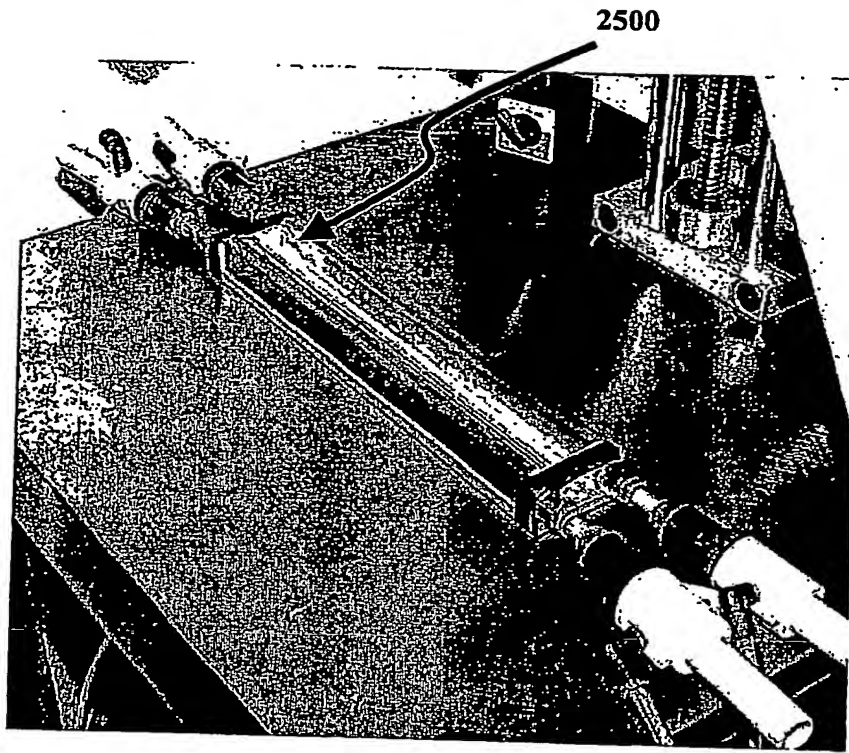


FIG. 25

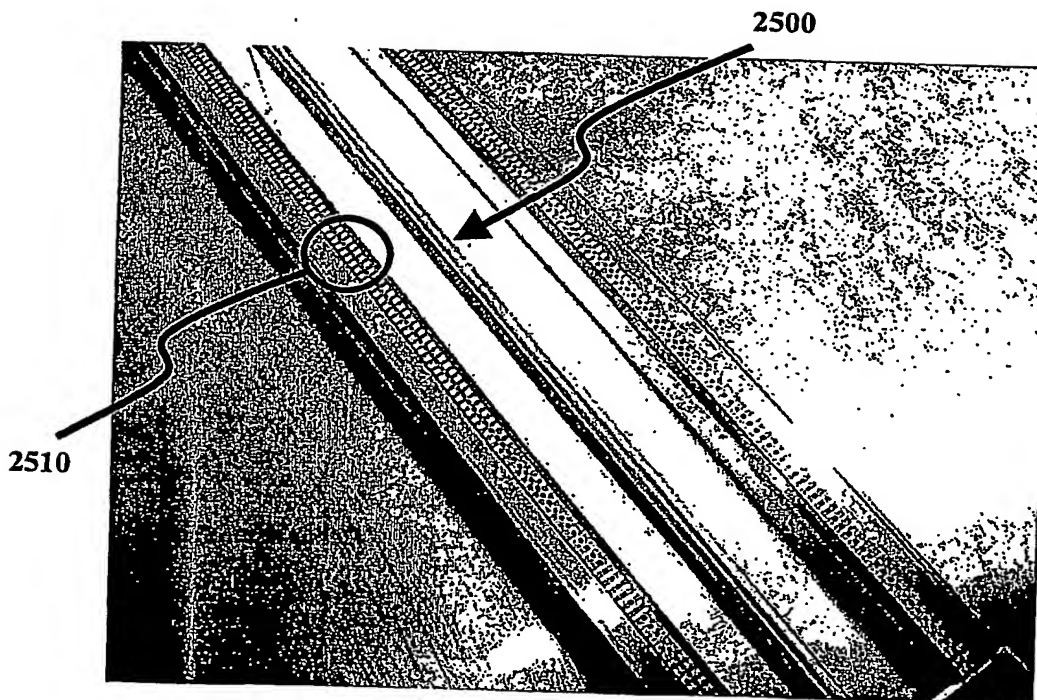


FIG. 26

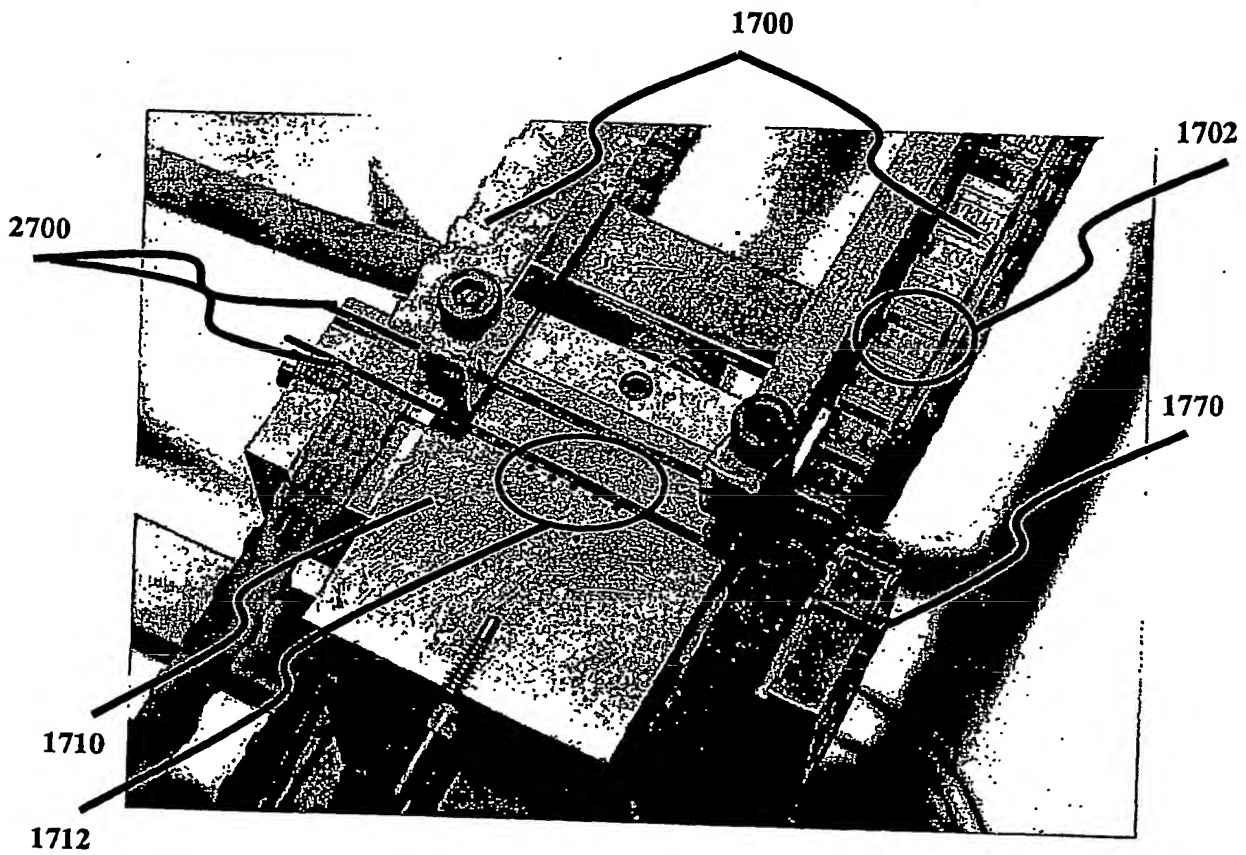


FIG. 27

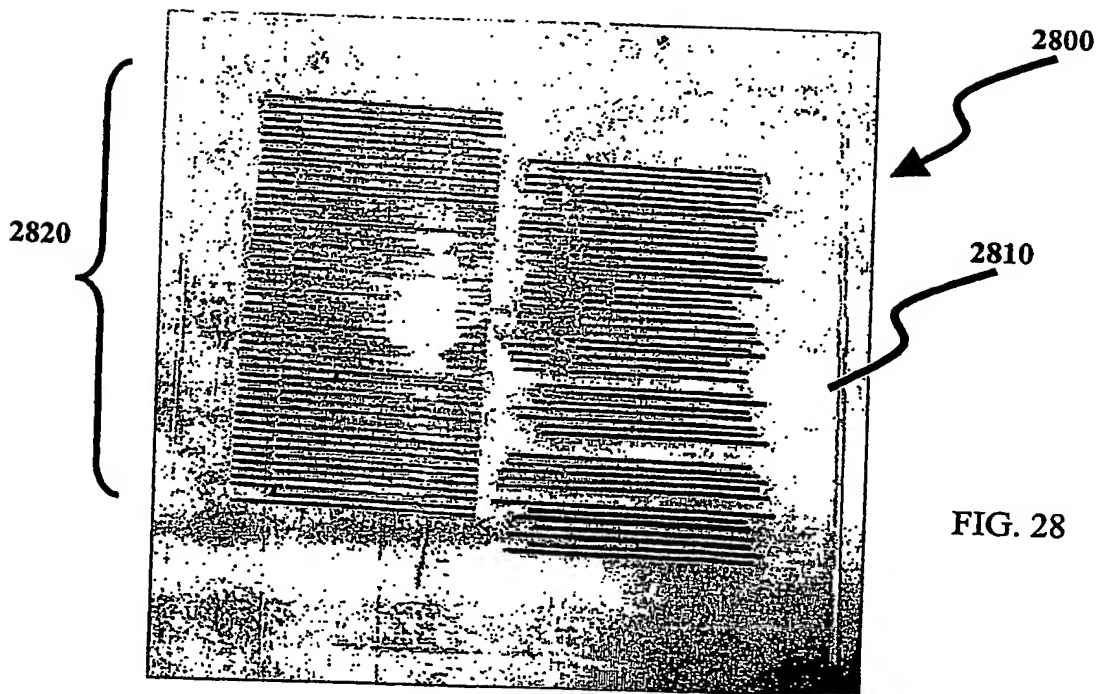


FIG. 28

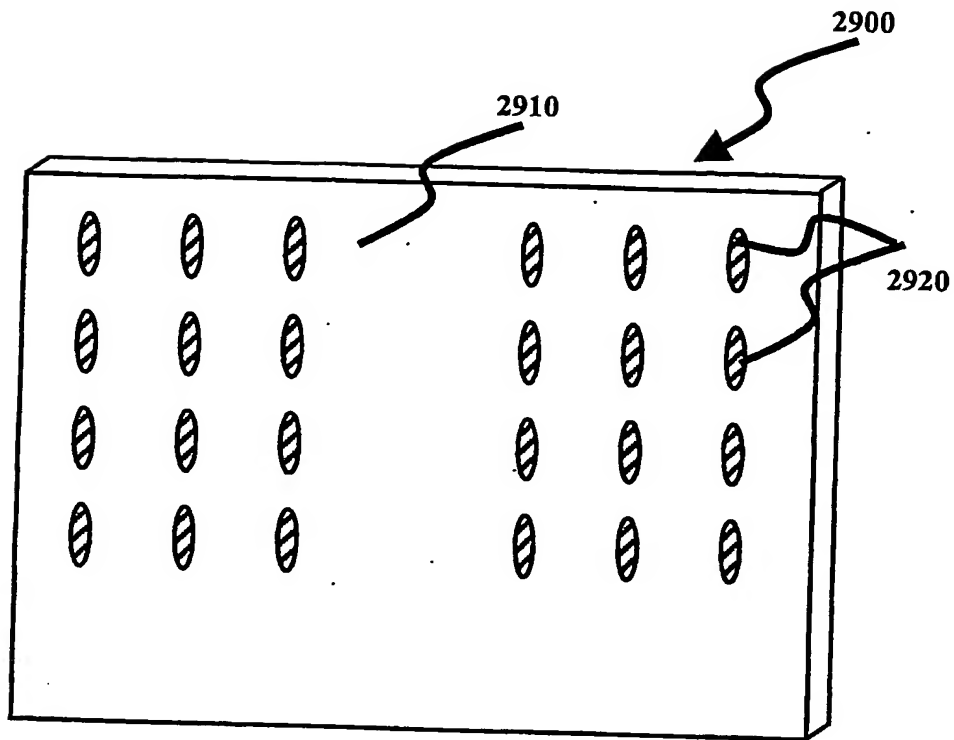


FIG. 29

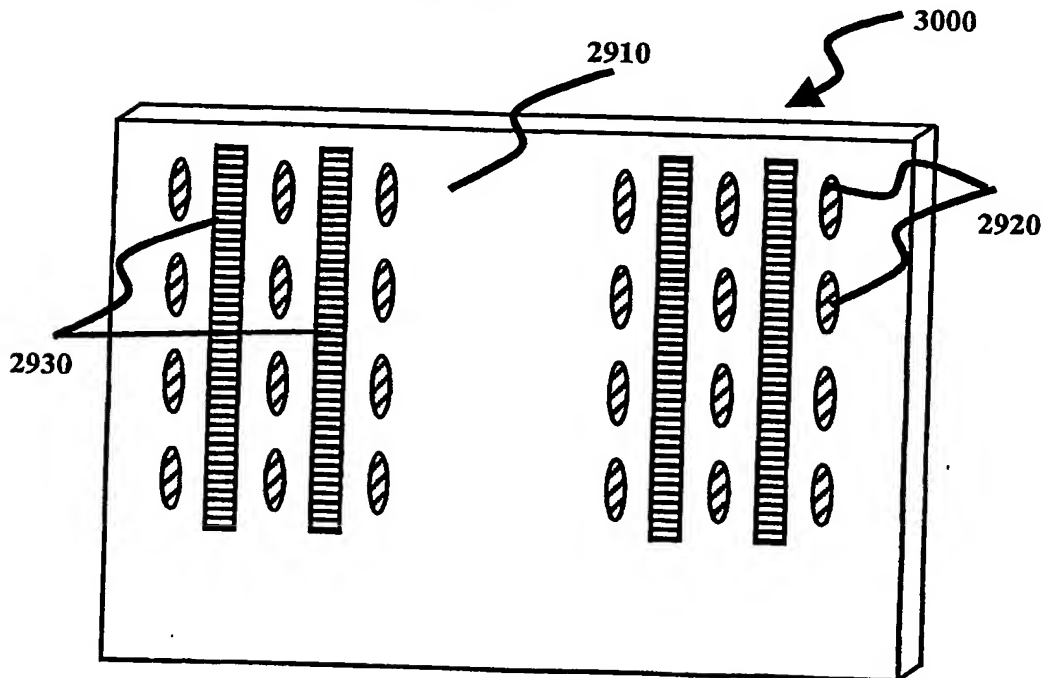


FIG. 30

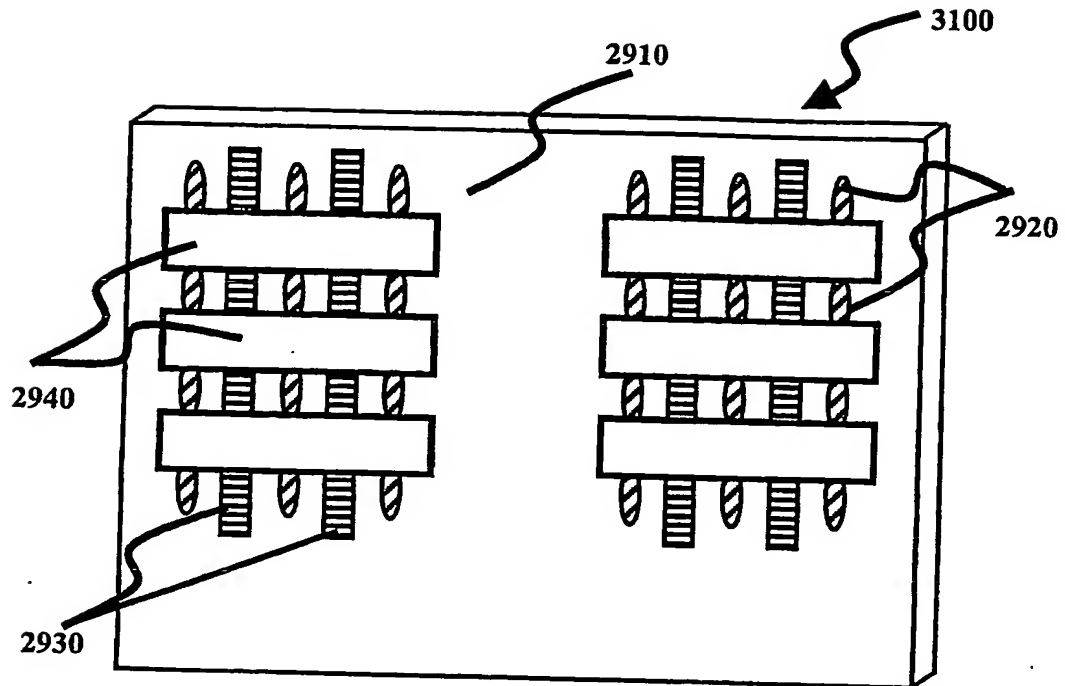


FIG. 31

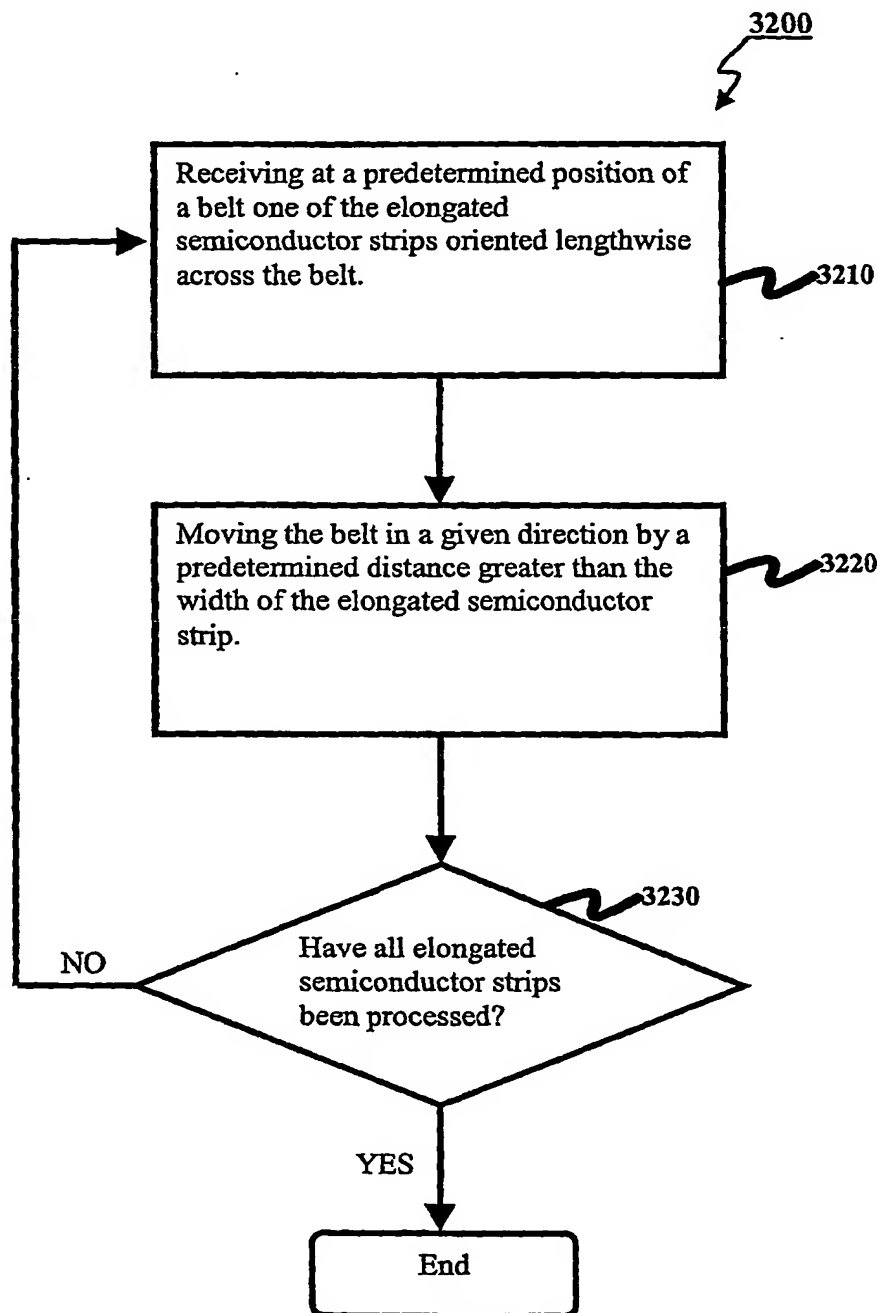


FIG. 32

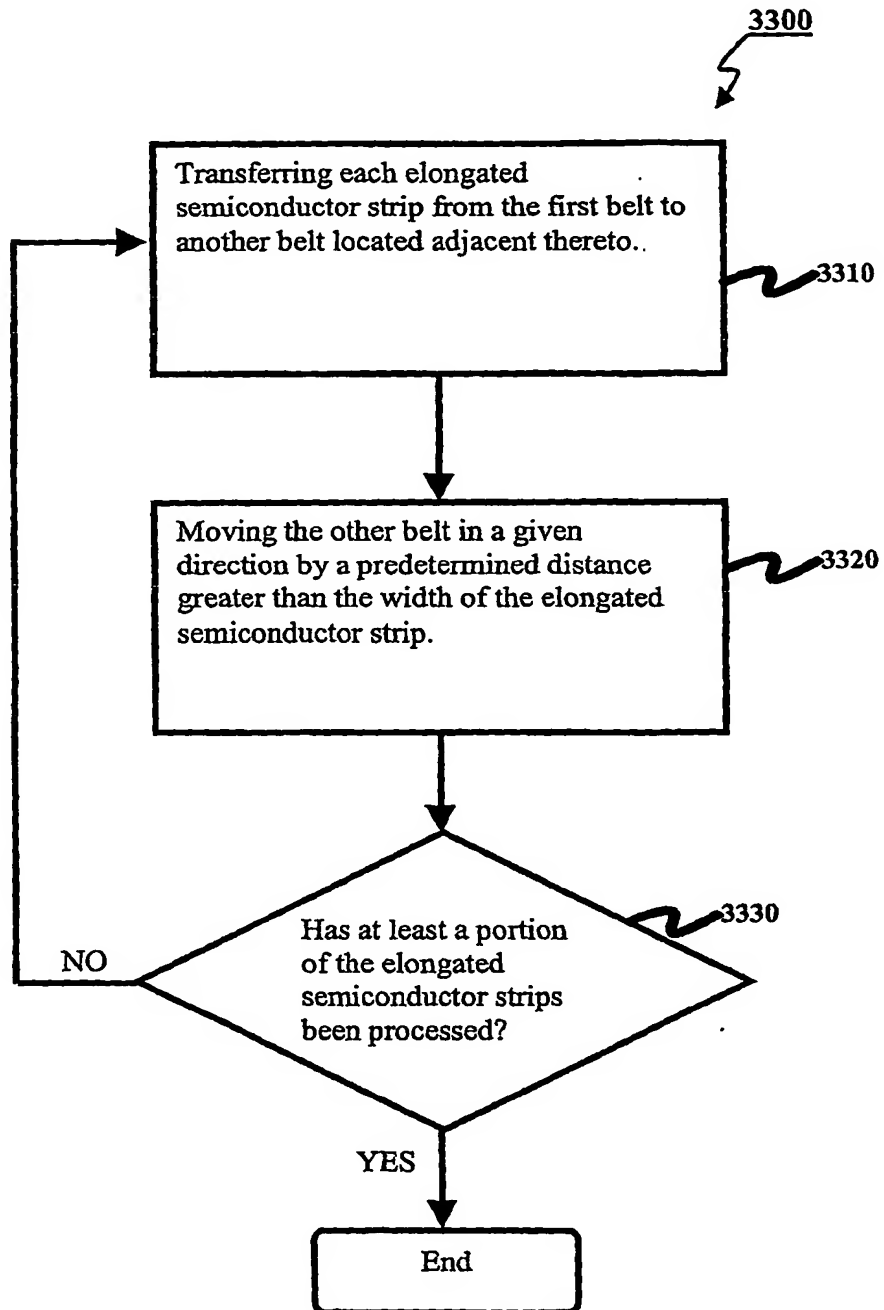


FIG. 33

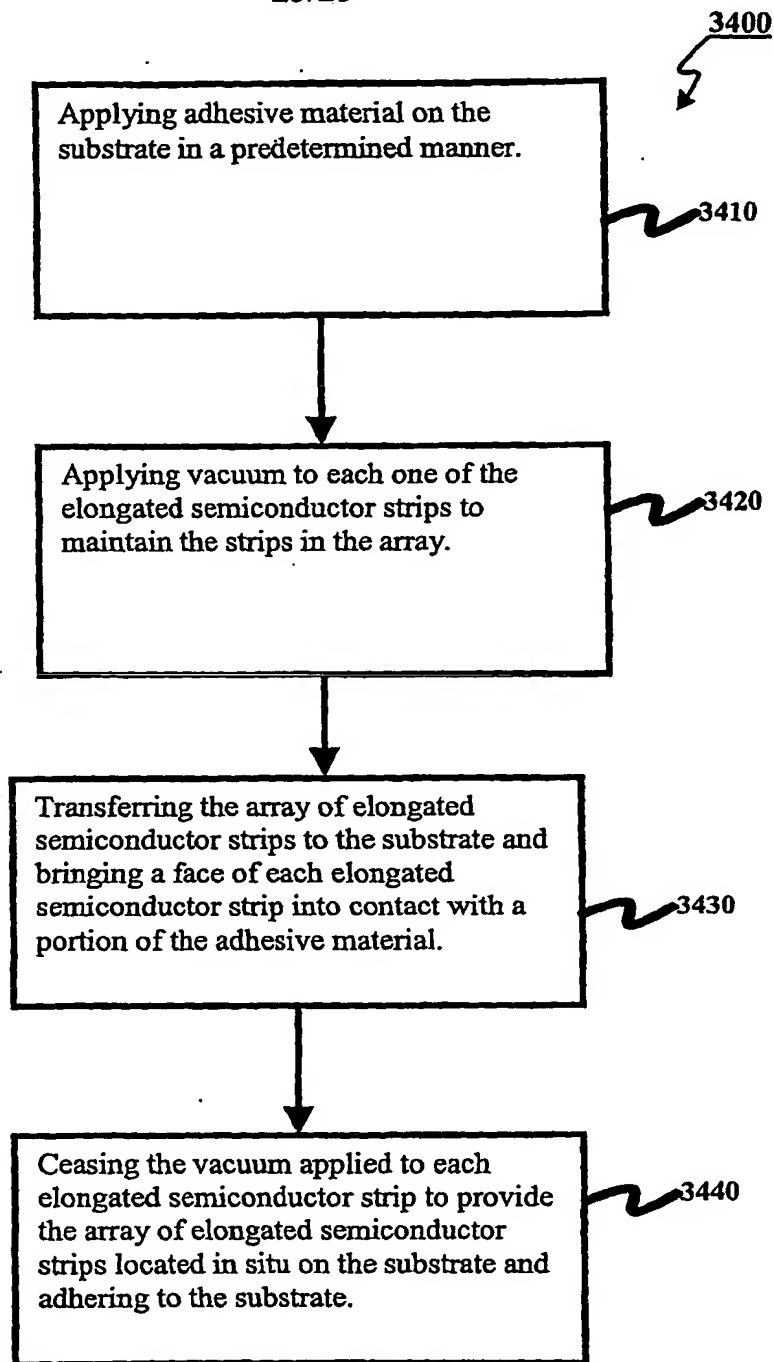


FIG. 34

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